MASSACHUSETTS INSTITUTE OF TECHNOLOGY

RN-59

Temperature Readout System for a Strapdown Gyro System

J.T. Egan

June 1970

MEASUREMENT SYSTEMS LABORATORY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE 39, MASSACHUSETTS

RN-59

Temperature Readout System for a Strapdown Gyro System

J.T. Egan

June 1970

Measurement Systems Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

Acknowledgements

This report describes approximately 25% of the work under NASA-ERC contract NAS 12-2085. The balance of the work was under the supervision of ERC. It is outlined in the monthly progress reports filed with NASA-ERC, and by its nature, this work requires no further documentation.

The publication of this report does not consitute approval by the National Aeronautics and Space Administration of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.

INDEX

RN-59

Temperature Readout System for a Strapdown Gyro System

by J.T. Egan

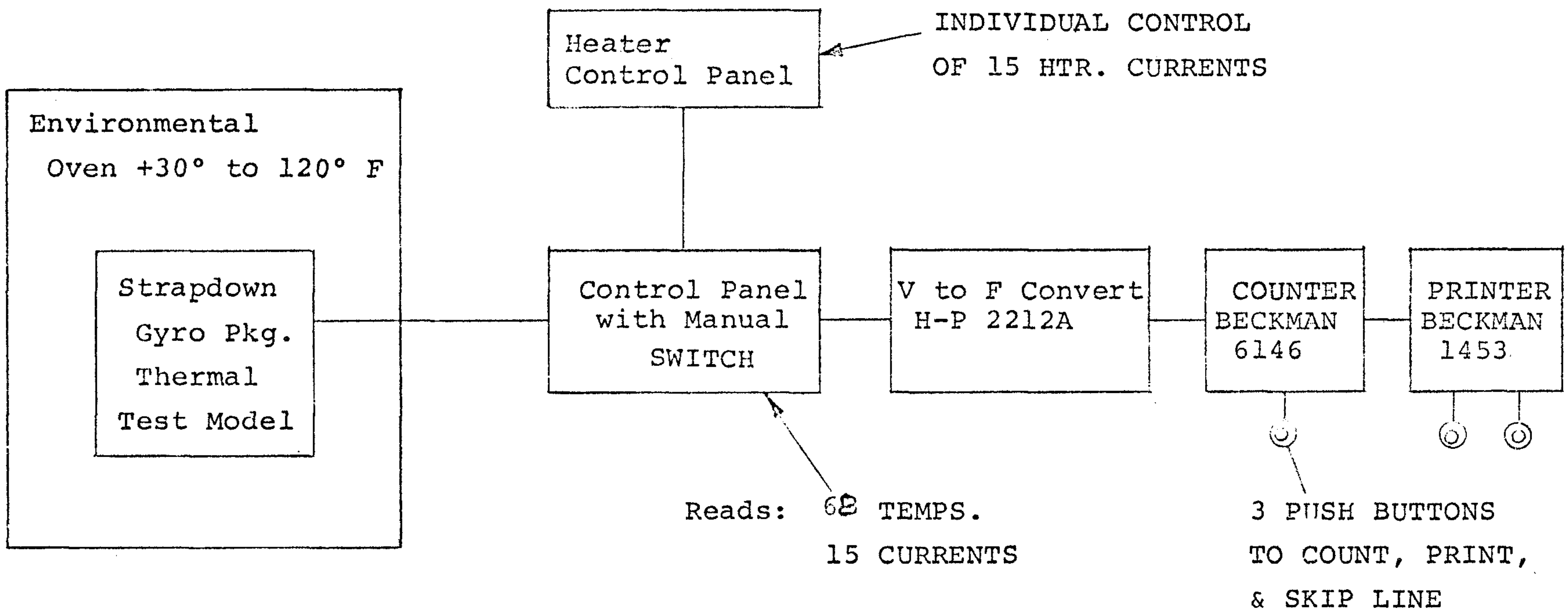
1. Abstract

This effort was to support NASA-ERC in investigating Inertial Measurement Unit (IMU) temperature control problems. We designed and built a system to monitor the complex temperature pattern of a strap-down IMU assembly while a thermal mock-up of the unit was undergoing environmental tests.

The work described herein may be summarized by the two block diagrams labeled "Phase I" and "Phase IIA" and the MIT-MSL dwg. D-7-118.

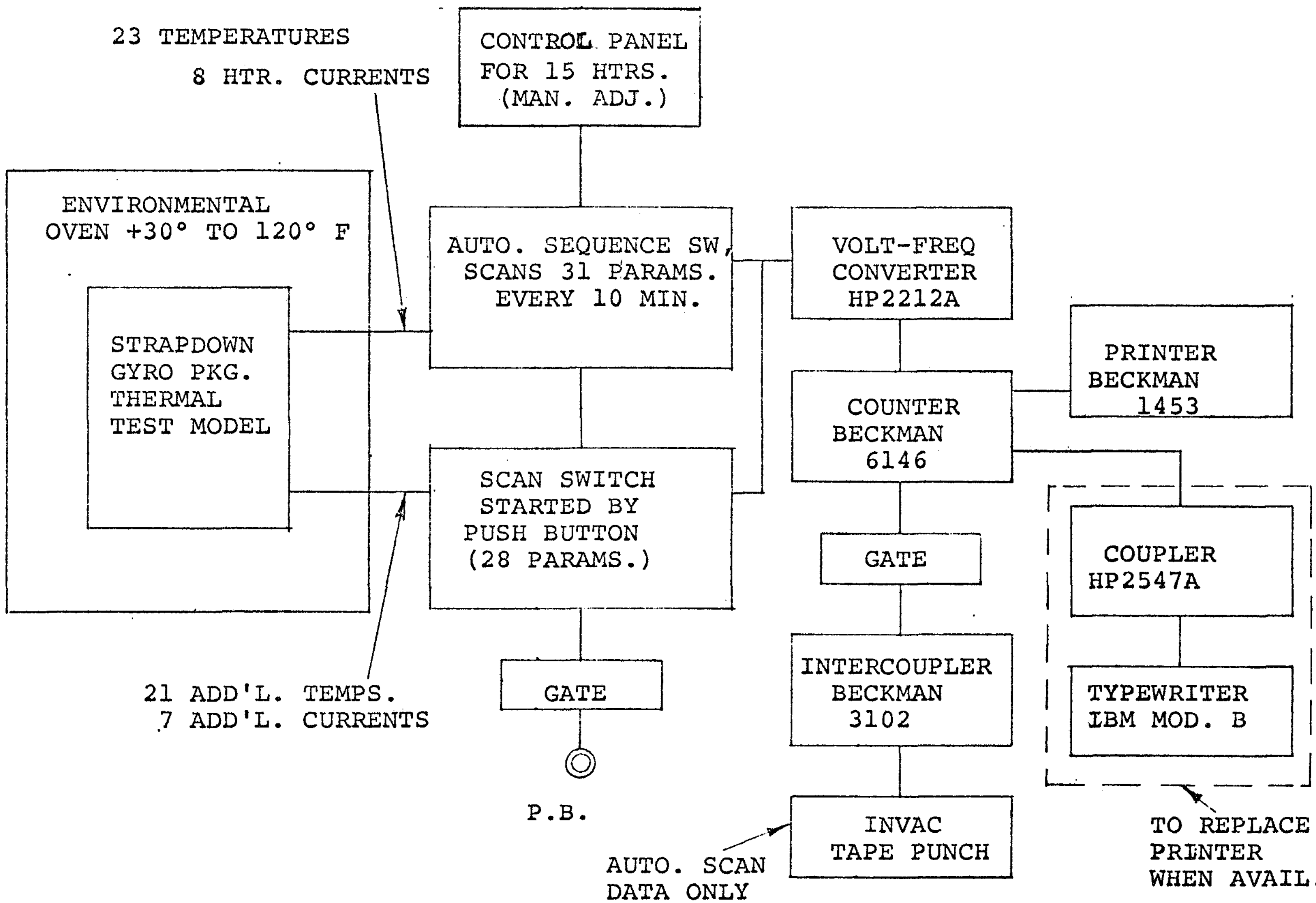
2. The Objectives

The objectives were to develop a readout method, test and evaluate the overall heat budget and the temperature distribution in an IMU system. A printed record of time, temperature, and heater current data displayed in an organized manner was a requirement.



Thermal Test of Strap-down
Gyro package Phase I

M.I.T.-MSL
Proj. 71511
J. T. Egan 1 May '69



Thermal Test of Strapdown

Gyro Package Phase IIA (Revised)

M.I.T.-MSL
Proj. 71511
J.T.Egan
August 1969

3. Phase I

In phase I we instrumented a strapdown gyro block furnished by NASA-ERC (Honeywell dwg. No. DGG 8066Al) as follows:

1. We added 59 nickle wire temperature sensors to the assembly (See Dwg. D-7-112B, -115A, 116, & -117).

2. We designed and made a dummy variable impedance (D-7-100C) to replace the original "variable thermal impedance".

3. We designed and made a dummy electronics package as a substitute for the proposed electronics. This device simulated the size and heat output of the expected final design. (See Dwg. D-7-101-B).

All wiring was made compatible with existing block harnesses. A switching panel (D-7-102) was also made which could manually switch any one of the 66 temperatures or 15 current sensors into a digital voltmeter for printout. (See block diagram "Phase I"). The above switching panel included a board with 6 bridges and 78 adjustable resistors (D-7-111-B) for the temperature sensors as well as a current control and readout calibration potentiometers for each of 15 heaters. (See D-7-102, & 108E)

In phase I we tried to calibrate our bridges by balancing each bridge at 0°F and then setting each bridge to 14722 (15000-278) counts with the sensitivity potentiometers when the chamber was held at 150°F. for 24 hours. We then added 278 counts by altering the balance pots.

The tests showed that the minimum heat requirements and maximum environmental temperatures were compatible. Typically these conditions require that each gyro have a minimum heat input of 4.7 watts; each accelerometer, 1. watt; and the dummy electronics package 32 watts (or 49.1 watts total) in an environment of 120°F at atmospheric pressure. It was a design requirement that the final gyro be maintained at 155°± 0.1°F and the accelerometers at 147.° ± 0.1°F. Eventually each unit will have its own servo controlled heater so for these tests the above 6 temperatures must be substantially less. Under the above conditions the 3 gyros were within 0.3° of 136.2°F and the 3 accelerometers were within 2.0° of 137.8°F.

Due to the slight misunderstanding the four thermal insulating mounts between the gyro block and main frame were assembled without the loose insulating washers. As a result the temperature drop across these buttons was less than it should be. At 49.1 watts input and 30°F ambient F6 minus F4 was about 7°F (data pg. 2 dated 13 June 1969) and about 18°F when this assembly error was corrected. (See comparable

Phase II data 23 Feb. 1970).

We believe the unusually high temperatures of about 260°F for T13 and T14 on D-7-101B (See data pg. 3 dated 15 June 1969) to be essentially correct and shows that our thermal contact between the dummy electronics package and the gyro frame was not realistic.

Phase I was completed but the gyro block components were required by NASA on short notice for flight tests beginning about mid June. Five pages of temperature and heater current data were hurridly taken and given to NASA-ERC for evaluation. Time did not allow us to repair faulty sensors or refine our calibration. The evaluation and improvement of this system will be discussed under Phase IIA.

4. Phase II

Under phase IIA the instrumentation work was developed during the summer but the required gyro block was not returned until late in September. Many alterations in the block configuration were then necessary due to design changes. We also felt that our original calibration techniques left much to be desired.

Design changes and discussions with NASA-ERC personnel led to a reduction in the number of parameters from 66 temperatures and 15 current measurements to 44 temperatures and 14 currents.

When the word arrived late in December that the future of the project was in doubt we decided to sacrifice certain refinements in the interests of a working system at minimum cost. The details will be explained in the following pages.

The questionable integrity of temperature data indicated to within 0.01°F while using nicle wire sensors was acceptable to NASA personnel because this data would show the direction of small temperature changes.

The strapdown gyro system has been designed to use 8 independent temperature servo controls. (Tentatively each of 3 gyros will be held to 155° $\pm$ 0.1°F; each of 3 accelerometers to 147° $\pm$ 1.°F; and the gyro block and electronics package to 140° $\pm$ 1°F.) The remaining 6 block gradient heaters (BGH-1 etc.) are to be trimmed manually.

The system ground rules require that the 3 gyros have a 6 watt minimum power input to each, and the electronics assembly is to dissipate at least 28 watts to give 46 watts total input. The internal block, on which all gyros and accelerometers are mounted, has one heating blanket for overall block temperature control and 6 gradient heaters for block temperature distribution control. In phase II the heating current to all 14 of these heaters are controlled manually.

The environmental requirements are 30° to 120°F at atmospheric pressure. It should be noted that all tests were conducted with the chamber fan blowing on the block unless otherwise specified. During all tests the strapdown package was in intimate contact with our large mounting box - a good heat sink with a large surface area. (See D-7-117, & -118) In the writer's opinion the final use of the sysem will find this mounting box replaced by a vibration isolation mount which - by nature - will provide a high resistance path for the flow of heat. All data taken in this program could be compromised by altering the mounting and forced air cooling details.

A critical evaluation of phase I led to the following design requirements for phase II:

1. Present the measured data (including time) efficiently.

2. Use a separate bridge with two very sensitive adjustments for each sensor.

3. Minimize sensor self-heating effects.

4. Provide an independent real temperature reference.

5. Minimize the temperature readout errors in the 70° to 150° F region.

6. Provide better temperature calibration features and techniques.

7. Minimize all errors due to moisture.

8. Provide maximum flexibility at reasonable cost.

We designed and made parts of a system as outlined in block diagram "Phase IIA". This instrumentation will tabulate immediately the output of each sensor in its own column and place all pertinent data associated with a test run in an organized manner on one reproducible page (See copy reduced in size dated 20 Feb. 1970). It will also display earlier and current information in a way which will allow evaluation with a minimum of searching, and adjustments without interrupting a test. The more important 31 parameters are typed out at 10 minute intervals as part of the "automatic sequence" and less variable measurements may be recorded as required by pushing a button to initiate the "manual" readout cycle. The column and row spacing are distinctly different to avoid confusion. Rolls of 22" wide tracing paper can be used but we found that ordinary "D" size (22" x 34") tracing paper was about the largest convenient size.

A clock to print out the first column of data in accumulated minutes was started but not finished. Time shown in hours and minutes might be more convenient for the operator but would be very expensive and it would complicate the plotting of data vs. time. Accurate time cannot readily be expressed as a voltage level so a mechanical switching system feeding directly to the typewriter seems to be the most practical method. The last column of the automatic readout sequence is labeled "STD". Only readings taken after 12 Mar. 1970 are meaningful. These numbers show the voltage across a voltage divider and serve as an indication of the repeatability of the stabilized power supply and the digital volt meter combination. To date this number has had readings of 58489 $\pm$ 8 counts. The large number, 5XXXX, was chosen as an "end of scan" reference mark for possible automatic curve plotting considerations.

A separate plug-in card was provided for each sensor type - about 10 bridges each on 5 cards. (See Dwgs. C-7-125C, -126B, -127, & -128). It was found in practice that the adjustment of R_B was not sensitive enough and on some occasions they could not be adjusted to give a number within 30 counts of the desired reading.

The platinum sensor detail is shown in Dwg. A-7-147. This thermometer with the entire testing block (Dwg. A-7-137A) was centered in the dummy electronics package and supported by strings for the entire test program.

The platinum sensor (A-7-147) may be inserted in the dummy Z axis gyro (C-7-145) and the decade box and Z1(C-7-136B) set so that the CAL station on this drawing will read 00000 when the desired temperature is attained. Unfortunately this number will not distinguish between a temperature which is too high or too low. A false zero of 100 counts (1 mv unbalance) might be a more useful technique.

Late in September we obtained on loan a Fisher Constant Temperature Oil Bath which - by test - would hold any temperature between 80° and 155° F constant within .01°F for a period of an hour or so. We also made our thermal test block (A-7-137A) for use in this oil bath or a separate ice bath. This fixture was wired to be completely compatible with our control panel and readout system and included the sensor identification terms such as T2', T9', F2', F10', GXT' & GYT' which are to be used to locate the proper switch positions.

The testing block (A-7-137A) has 2 each of our more important sensor types and the platinum reference thermometer. By design we expect all seven sensors to be within .005°F of the same temperature under steady state conditions when used in our oil bath or ice bath. Our intent was to measure the accuracy, consistency, and linearity of our sensors but in practice it demonstrated the shortcomings of our techniques. We could see and evaluate the effect of 5 milliwatts of self-heating power and also the "settling time" after switching required by the digital voltmeter. Good laboratory practice would require the oil and ice bath tests as outlined to be carried out in detail but this work is so time consuming and the results so intangible that we concentrated on more important errors.

We chose to linearize the output of our bridges by requiring the digital voltmeter to show a number proportional to the temperature of R_S in degrees Fahrenheit at the 70°, 110°, and 150° F points. This linearity was achieved by means of the following formula which is typical for the T--series of pure nickle sensors:

R_S at 70°F = 200 Ω = R_{70}

R_S at 110°F = 200 x 1.12635 = 225.27 = R_{110}

R_S at 150°F = 200 x 1.26001 = 252.00 = R_{150}

$$R_A = R_A' + \frac{R_D}{2}$$

$$R_A = \frac{(R_{70} + R_{150})R_{110} - 2\ R_{70}R_{150}}{R_{70} + R_{150} - 2\ R_{110}} = 698.83 \text{ ohms}$$

or 700 ohms

(See Figure 5)

This calculation was based on RdF data for C.P. Nickle given to 3 decimal places with the help of a little curve smoothing, and the bridge designs used these figures. The same computation with Minco Products, Inc. data given to 5 places gave a value of 755 ohms (See figure 4, pp. 1 & 2).

Each bridge has its own balancing potentiometer R_B and two 1 megohm bridge sensitivity adjusting resistors R_C and R_F (i.e. coarse and fine adjust) (See diag. C-7-127 - typical). Our recommended calibration procedure is as follows:

1. Insert a precision platinum resistance thermometer into the test package. Use an external nulling bridge to read the reference temperature to within 0.01°F. (See figure 6).

2. Enclose the entire gyro block unit in a close fitting box made of 4 inch thick styrofoam.

3. Set all R_C's and R_F's for maximum output (full clockwise) (See diags. C-7-125C, -126B, -127, and -128).

4. The assembly should be placed in a relatively air tight and insulated thermal test chamber and allowed to soak for 24 hours with all heaters and blowers turned off.

5. Record temperature measured with the platinum sensor. Read to within 0.01°F and be sure temperature drift is at a minimum. This temperature should be about 70°F - call it T_1.

6. Balance all 44 bridges by adjusting R_B in each case.

7. Set test chamber temperature for 150°F. The styrofoam box may be removed temporarily to save time but the block should still be soaked at 150°F for 24 hours after the box is closed.

8. Record temperature measured with the platinum sensor. Read to within 0.01°F and be sure drift is at a minimum. This temperature should be about 150°F - call it T_2 - and record for each sensor.

9. Set $T_2 - T_1 = C_3$ for each sensor. Adjust 1 megohm coarse and fine resistors so that digital voltmeter reads C_3 - (about 8000 counts) for each sensor.

10. By means of band switch #4 (BS 4) and the .01 to 1111.1 ohm decade resistor (C-7-136B) across terminals J5 and J6 (C-7-129D) record the value of a substitute resistance to within .005 ohm for each sensor which will give the same count on the digital voltmeter as each real sensor.

11. Return block in its styrofoam box to 70°F and soak for 48 hours in the test chamber and measure temperature to within .01°F.

12. Set all bridges by adjusting R_B to give a readout of 3740 counts $\pm$ any deviation from the nominal 70.00°F.

13. Reset readout by adjusting R_C and R_F for each sensor to give the number of counts equal to the measured temperature in above item 10.

14. Place the decade resistance box between J5 & J6 and adjust for the apparent resistance of a given sensor at 150° while the block is at 70°. The readout system can then be switched by BS 4 from 7000 counts to 15,000 counts repeatedly for a two point linear calibration of each temperature sensor. It should be understood that in this section 7000 and 15,000 counts are nominal numbers and should be adjusted for the real values preferably within ± 300 counts of these numbers.

It usually takes over an hour to run through all sensor adjustments and each sensor is being heated by its own current for about 1.5 minutes during an adjustment cycle.

Typically the temperature drift of the gyro block in a well-insulated enclosure might be about 0.3°F (30 counts) per hour and the self-heating effect might account for another 30 counts of uncertainty. Sensors T02 and T09 measure air temperatures and their very small masses make them especially sensitive to self-heating. In normal use each sensor is energized for 2 seconds every 10 minutes so this is only a calibration problem.

The 2 point calibration technique using the BS4 has not been tried but the writer considers this concept essential for good calibration.

The set heater current might change 2 or 3% between the "cold" resistance and later "hot" resistance of each heater so trimming for steady state conditions is recommended.

All phase II tests had a desicant spread around the chamberfloor and dry nitrogen was fed into the block housing during cooling cycles and occasionally during cold runs. A thin transparent frost formed on the coldest run (Feb. 25 see T6 & T10) although we took all practical steps to seal the chamber.

5. Test Results

The test results are shown on the second page of our typed data sheets dated 20 to 25 February 1970. These tests included steady state environmental conditions of 120°, 80°, and 24°F. all with an input of 46 watts for heating. Another run was completed at 24° with 12 watts in the block heater in addition to the above 46 watts.

Note that on all block heater current readings (BSC) from 1350 23 Feb. to 25 Feb. we exceeded the current reter range so that 01685 really means 1.017 amps.

The air temperature T09 is essentially correct for an instantaneous chamber air temperature reading but should be averaged to obtain a useful reading. At 30° the chamber cooler ran for about 67 seconds for each 8 minute cycle giving a saw tooth temperature variation of about 16 degrees. We suggest a corrected average temperature of 24° for the intended 30°F chamber temperature.

The three typed calibration and data sheets given to NASA to date have had the time (0000 to 2359) and the column headings typed manually.

We typed two numbers at the right end of some lines which show the resistance of the platinum reference thermometer in ohms and the computed real temperature in degrees Fahrenheit.

It should be noticed that we adjusted the spacing of our data for clarity so time references become critical to an understanding of the results.

On 24 Feb. the measured heater currents were as explained in words on the data sheet but the heater current readouts were not independent of each other. This behavior was corrected by 9 March. After this date the current scale factor was changed by a factor of 10 (i.e. .5 amps was 50000 counts and now equals 05000 counts).

We had some trouble with our 500 ohm bobbin type CP Nickle sensors - about 6 of them opened up while epoxied in place. All were mounted in the specified manner. We "saw" the GXT snesor open on 21 Feb. at 1410 and AZT on 20 Feb. (see data sheets).

The temperature tests may be separated into 3 main categories: calibration tests with the gyro unit in its styrofoam insulated box; test runs with the heaters at the required power levels; and other test and calibration procedures. We have drawn a vertical line along the left end of what we consider useful data runs dated 20 to 24 Feb. The sensors GXT, AZT, T11 and F11 were faulty. They were replaced by 9 March, but were not effectively recalibrated.

6. Design Flexibility

As our system now stands it can be used to tabulate any parameter which can be expressed as a voltage or, within limits, time. It can print up to 8 digits and 12 additional characters per word in any number of columns from 1 to 99 subject to the limitations of a single word format and a 22 inch page width. It is also compatible with a Hewlett-Packard model 2801A quartz thermometer system. This instrument can give 2 or more absolute temperature references in the same format and its counter can replace the more expensive one shown in the block diagram phase IIA. (We used the more expensive counter because it was available.)

We experienced some trouble in getting smooth repeatable temperature readings and our efforts may be summarized as follows:

The input of the voltage to frequency converter (Fig IIA) must look into an impedance of about 1000 ohms. It became necessary to add a 60 cycle filter and a voltage follower circuit to the converter input. A simple integrated circuit type of an impedance matching voltage follower was tried but it had drift characteristics which were difficult to pin down. As a temporary expedient we removed the voltage follower and the 1.5 and 0.9 megohm resistors in the bridge circuit (fig 5) and replaced the two 2 second timers shown on drawing C-7-131-C with a more elaborate adjustable time switch. This technique allowed about 6 seconds settling time for switching transients to die out before the digital voltmeter started its one second cycle. We recommend that a high quality voltage follower be used before the digital voltmeter and that all circuits be converted back to the original design configuration.

This temporary expedient made it necessary to omit such features as the variable column spacing, a gating system which protected the readout sequence from operator error, the withholding of meaningless numbers, and the automatic tape punch feature.

We had some trouble with the Hewlett-Packard coupler. A company service engineer could not identify the flaw in 3 days of testing and it seemed so trivial we did not send it back to the factory. The malfunction can be easily circumvented by starting each word with a "space".

7. Conclusions

In the writer's opinion the system as outlined in phase IIA could - if fully exploited - result in the following specifications in the 70° to 150°F temperature range:

1. absolute accuracy $\pm$ 0.3°F or $\pm$ 0.1°F if corrections are applied for known nonlinearities

2. resolution and repeatability $\pm$ 0.02°F

By "fully exploiting" the systems potential the writer means:

1. Inserting a high grade voltage follower ahead of the voltage to frequency converter.

2. Changing all R_B's (Figure 5) from a single pot to two pots of widely differing values in parallel.

3. Using the remote voltage sensor on the bridge power supply as close to the bridges as practical.

4. Periodic calibration of the voltage to frequency converter.

5. Using a constant temperature oil bath for the more critical sensor calibrations. (Messy, time consuming, and usually impractical for components larger than a baseball.)

6. The meticulous use of strain free platinum temperature calibration resistors and associated wheatstone bridge equipment, ice baths, etc. for absolute temperature

reference.

7. The use of very well insulated constant temperature enclosure which by definition will bring all sensors to the same temperature.

8. The use of a two point linear calibration technique (described elsewhere) which will allow the operator working on any given sensor to switch at will from a real, measured, and accurately known temperature - typically about 70°F - to a previously measured and accurately simulated higher temperature - typically 150°F.

We would also recommend the use of a good quality sensor all of which are made from the same material. The block as now instrumented has some "pure nickle" sensors and others (F-- and K-- series) are "nicle A". The pure nickle seems preferable because the documentation of the physical properties is more complete.

We would also suggest that the readout intervals of 5 min., 10 min. or 30 minutes be available and that this timing and one to three switches for heater currents be programmable for a 24 hour period. Experience has shown that a single variable resistor for R_B (see Fig. 5) was not sensitive enough to allow the readout to be adjusted to within 2 or 3 counts (.02 or .03°F). This limits the calibration accuracy and we would suggest that R_B be replaced with 2 pots of widely differing values - connected in parallel - to improve the calibration accuracy. Another worthwile feature (shown on diag. D-7-130B) is the use of a visual indicator or drum attached to each band switch for easy reference during calibration.

Appendix I

Figures

MIT - MSL PROJECT 71511
FEB. 20, 1970
J. T. EGAN

FEB 20, 1970 1015 STRAPDOWN THERMAL TEST NO CHAMBER HEAT 6 WATTS ON EACH GYRO AND 28 WATTS ON DUMMY ELECTRONICS PACKAGE (SINCE FEB 19 1640)

SET CHAMBER TO 120° F

PLATINUM REF. BLOCK (A-7-137-A & -147) CENTERED INSIDE DUMMY ELECTRONICS PACKAGE AIR SPACE - NEAR EP HTR. AND T13 (SEE DWG. D-7-142-A)

597.86 OR 153.70°F

601.97 OR 157.85° F

AT 1710 FEB 20 SET CHAMBER COOLER TO 80° F

THIS RUN AT 0845 FEB 21

562.44 OR 119.33° F

562.19 OR 119.08° F

CKT. BRD. OUT FOR GXT

561.97 OR 118.87° F

AT 1235 FEB 21 SET CHAMBER FOR 30° F 24.0°F = Better average

READJ CHAMB. TO 30° F

540.60 OR 98.16° F

24.5°F aver. (corrected)

FEB 23, 1970 CHAMBER AT 30° F SINCE NOON FEB 21 GXT, AZT, T11, ARE OPEN AT SENSOR F11 INOPER. (T) CHAMBER COOLING CYCLE ON 67 SEC PER 8MIN CYCLE

508.50 OR 47.18° F

507.21 OR 45.94° F

506.81 OR 45.55° F

AT 1350 ADDED 12 WATTS TO BLANKET HTR. BSC

NB 1.017 AMPS

506.99 OR 65.73° F

507.25 OR 65.98° F

FEB 24 NB INTERACTION OF HEATER CURRENT READOUTS: GYROS SET FOR .340 AMPS , EPC .966 A , BSC (CONTROL HEATER) 1.00 A (INTO 50, 30, 412 OHMS RESP.) MEASURED TOTAL HEATER INPUT CURRENT 2.90 AMPS. OTHER HTR CUR. ARE APPROX ZERO

509.73 OR 68.36° F

509.51 OR 68.14° F

CHAMBER HEATER AND ALL BLOCK HEATERS OFF AT ABOUT 1100 HRS. 2/25 CHAMBER BLOWER TURNED OFF AT 1700 HRS. 2/25

522.67 OR 80.83° F

525.90 OR 84.04° F

517.99 OR 76.29° F

OBSERVE DATES

Fig. 1 Sample Data Sheet

Plat. Ref.	147.69°F	71.17°F		147.85°F	71.18°F
	2/19 1100	2/26 1310		2/19	2/25 1305(1:05PM)
	Set	As is		Set	As is
GXT	~~14704~~	09890	F04	14782	07093
GYT	14728	06991	F06	14782	07093
GZT	14733	07062	F05	14793	07073
AXT	14733	07130	F07	14775	07935
AYT	14725	07129	T10	14775	07215
AZT	~~14730~~	06373	T12	14765	07196
BST	14710	06619	T13	14794	05894
(T15) INT	14707	07118	T11	~~02352~~	~~11478~~
BIT	14722	06948	F09	14799	07069
B2T	14718	06898	F11	~~13345~~	~~05647~~
B3T	14726	06922	F12	14790	07056
B4T	14730	06913	F15	14795	07089
B5T	14725	06936	F14	14793	07132
B6T	14720	07686	F13	14805	07129
T02	14717	06705	F17	14787	07160
T09	14703	06704	K02	14796	07146
T06	14749	07081	K01	14791	07139
T16	14729	07101	K11	14793	07217
T17	14734	07139	K13	14794	07199
T14	14738	07032	K14	14797	07178
F02	14765	07103	K16	14788	07168
F10	14771	07095	K17	14798	07163

"Set" means these temps. were trimmed with adjusting pots (over a period of 1 hour) to agree with the "platinum reference." The IMU system was enclosed in an insulating styrofoam box in a chamber set for 150°F. "As is" temperatures were recorded without adjustment 26 hours after the data runs and after all heaters were turned off-without the styrofoam box.

GXT and AZT failed during test

T11 and F11 failed before test

Fig. 2 Typical temperature readings for calibration.

MIT-MSL
Proj. 71511
J.T. Egan
2/24/70

These parameters were selected for automatic read out during thermal tests on Strapdown IMU Package (Honeywell Drwg. DGG 8066A1). The 31 values are typed out every 10 minutes.

	MIT-MSL Dwg. No.
*GXT = Gyro X axis temperature	C-7-145A
GYT = Gyro Y Axis temperature	C-7-145A
GZT = Gyro Z axis temperature	C-7-145A
AXT = Accelerometer X axis temperature	C-7-141
AYT = Accelerometer Y axis temperature	C-7-141
AZT = Accelerometer Z axis temperature	C-7-141
BST = BSR-1 Temp. sensor near block temp. control blanket. Honeywell Dwg. D34003327	D-7-115
INT(T15)- Thermal impedance (side nearer block)	A-7-157
**GXC = Gyro X axis heater current (50 ohms)	C-7-145A & D-7-108E
GYC = Gyro Y axis heater current (50 ohms)	C-7-145A & D-7-108E
GZC = Gyro Z axis heater current (50 ohms)	C-7-145A & D-7-108E
AXC = Accel. X axis heater current(135 ohms)	C-7-141 & D-7-108E
AYC = Accel. Y axis heater current(135 ohms)	C-7-141 & D-7-108E
AZC = Accel. Z axis heater current(135 ohms)	C-7-141 & D-7-108E
BSC = Control heater current (Honeywell Dwg. D34003327 (12 ohms)	
EPC = Dummy electronics Pkg. Heater current (30 ohms)	D-7-142-B

* Typical temperature read out 14721 = 147.21°F. (also = .14721 volts)

** Typical current read out 03000 = 0.300 amps

FIG. 3. SENSOR IDENTIFICATION PG. 1

BIT = SR-1 Temp.	See Honeywell dwgs. D34003327 & -3348 Pg.3 & MIT-MSL Dwg. D-7-115	
B2T = SR-2 Temp.		
B3T = SR-3 Temp.		
B4T = SR-4 Temp.		
B5T = SR-5 Temp.		
B6T = SR-6 Temp.		
TO2 = Air temp. around Gyro block		D-7-117
TO9 = Air temp. in test chamber		D-7-117
TO6 = Outer Mounting Frame		D-7-117
T16 = Thermal impedance (side away from block)		A-7-157
T17 = Thermal impedance (RIM)		A-7-157
T14 = Dummy electronics package at mounting surface		D-7-142B
F2 = Inner wall temp. of base (mounting frame)		D-7-116
F10 = Gyro adapting block temp.		D-7-115
STD = Set to 58500 counts. Monitors bridge supply voltage and voltage to frequency converter. Also serves as an "End of Scan" Ref. for punched tape.		C-7-125D

FIG. 3. PG. 2

These parameters were selected for occasional readout

	Dwg. #
F04 = Leg on base SW corner near high thermal resistance mount for block	D-7-116
F06 = Mtg. Lug on block near high thermal resistance mount post	D-7-115
F05 = Mtg. Lug on block NW corner	D-7-115
F07 = Mtg. Lug on block SE corner	D-7-115
T10 = Outer wall temp. of electronics housing	D-7-142-B
T12 = Center of electronics pkg. housing	D-7-142-B
T13 = Heat source within dummy electronics pkg.	D-7-142-B

B1C = Block gradient heater current -BGH-1 (28 ohms)

B2C = BGH-2 (52 ohms)

B3C = BGH-3 (52 ohms)

B4C = BGH-4 (52 ohms)

B5C = BGH-5 (52 ohms)

B6C = BGH-6 (52 ohms)

See Honeywell Dwgs.
D34003327&-3348 Pg.3
& MIT-MSL Dwg. D-7-115

T11 = Near outer wall of electronics housing	D-7-142-B
F09 = Gyro adapting block - may be mounted in any one of the 3 positions. (See F10 on automatic readout record)	D-7-115A
F11 = Same as F09	D-7-115A
F12 = Same as F09	D-7-115A
F15 = X axis accelerometer mounting block	C-7-141
F14 = Y axis accel. Mtg. block	C-7-141
F13 = X axis accel. Mtg. block	C-7-141
F17 = Lower outer corner of block near X axis Gyro	D-7-115A

FIG. 3. PG. 3

K02 = Block temp. near foot of Y axis gyro		D-7-115A
K01 = Block temp. near foot of Z axis gyro		D-7-115A
K11 = Block temp. under Z axis accel.		D-7-115A
K13 = Block temp. under Y axis accel.		D-7-115A
K14 = Block temp. near foot of X axis gyro		D-7-115A
K16 = Block bottom flange under Z axis gyro		D-7-115A
K17 = WEB on block. Block web on X and Y gyros.		D-7-115A

FIG. 3. PG. 4

T(°F)	RATIO	T(°F)	RATIO	T(°F)	RATIO	T(°F)	RATIO
-80	.65142	-40	.77300	0	.89719	40	1.02642
-79	.65444	-39	.77607	1	.90036	41	1.02972
-78	.65746	-38	.77914	2	.90352	42	1.03306
-77	.66048	-37	.78221	3	.90668	43	1.03639
-76	.66350	-36	.78528	4	.90984	44	1.03973
-75	.66653	-35	.78834	5	.91300	45	1.04307
-74	.66956	-34	.79141	6	.91618	46	1.04640
-73	.67259	-33	.79448	7	.91937	47	1.04974
-72	.67562	-32	.79755	8	.92255	48	1.05308
-71	.67864	-31	.80062	9	.92574	49	1.05641
-70	.68167	-30	.80371	10	.92892	50	1.05975
-69	.68470	-29	.80680	11	.93211	51	1.06313
-68	.68773	-28	.80989	12	.93529	52	1.06651
-67	.69076	-27	.81298	13	.93848	53	1.06989
-66	.69380	-26	.81606	14	.94166	54	1.07327
-65	.69683	-25	.81915	15	.94488	55	1.07665
-64	.69987	-24	.82224	16	.94809	56	1.08003
-63	.70290	-23	.82533	17	.95131	57	1.08341
-62	.70594	-22	.82842	18	.95453	58	1.08679
-61	.70897	-21	.83153	19	.95774	59	1.09017
-60	.71201	-20	.83464	20	.96096	60	1.09359
-59	.71504	-19	.83774	21	.96418	61	1.09701
-58	.71808	-18	.84085	22	.96739	62	1.10044
-57	.72113	-17	.84395	23	.97061	63	1.10386
-56	.72418	-16	.84707	24	.97388	64	1.10728
-55	.72722	-15	.85017	25	.97714	65	1.11070
-54	.73027	-14	.85328	26	.98041	66	1.11413
-53	.73332	-13	.85639	27	.98367	67	1.11755
-52	.73637	-12	.85952	28	.98694	68	1.12097
-51	.73941	-11	.86265	29	.99020	69	1.12444
-50	.74246	-10	.86578	30	.99347	70	1.12791
-49	.74551	-9	.86891	31	.99673	71	1.13137
-48	.74856	-8	.87203	32	1.00000	72	1.13484
-47	.75162	-7	.87516	33	1.00330	73	1.13831
-46	.75467	-6	.87829	34	1.00660	74	1.14178
-45	.75773	-5	.88142	35	1.00991	75	1.14524
-44	.76078	-4	.88455	36	1.01321	76	1.14871
-43	.76384	-3	.88771	37	1.01651	77	1.15218
-42	.76689	-2	.89087	38	1.01981	78	1.15569
-41	.76995	-1	.89403	39	1.02312	79	1.15921

NOTE: $R_T = R_{32} \times$ RATIO; WHERE R_T IS RESISTANCE AT ANY TEMPERATURE T, AND R_{32} IS RESISTANCE AT 32°F.

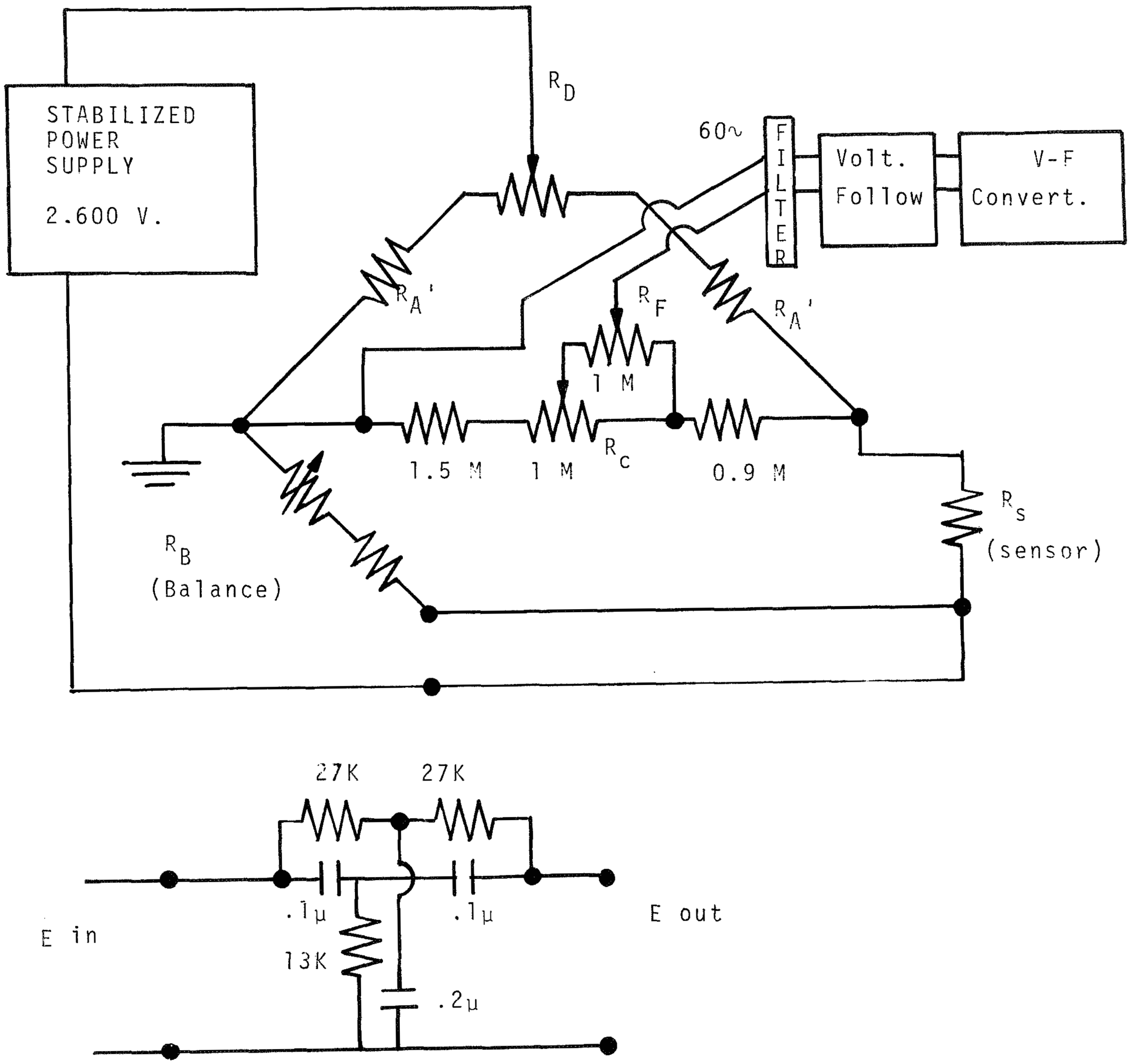
MINCO PRODUCTS, INC. MINNEAPOLIS, MINN.		RESISTANCE RATIO TABLE FOR CHEMICALLY-PURE NICKEL RESISTANCE THERMOMETERS	NO. 8
PREP'D. BY MKS	5/15/67		PAGE 2 OF 6
CHK'D. BY KS	5/15/67		REVISION:
APPR'D. BY JJ	6-20-67		

FIG. 4 PG. 1

T(°F)	RATIO	T(°F)	RATIO	T(°F)	RATIO	T(°F)	RATIO
80	1.16272	120	1.30707	160	1.45997	200	1.62185
81	1.16624	121	1.31077	161	1.46392	201	1.62598
82	1.16975	122	1.31448	162	1.46787	202	1.63012
83	1.17327	123	1.31824	163	1.47182	203	1.63426
84	1.17678	124	1.32200	164	1.47577	204	1.63845
85	1.18030	125	1.32576	165	1.47972	205	1.64264
86	1.18381	126	1.32952	166	1.48367	206	1.64683
87	1.18732	127	1.33328	167	1.48762	207	1.65102
88	1.19093	128	1.33704	168	1.49163	208	1.65520
89	1.19450	129	1.34080	169	1.49563	209	1.65939
90	1.19806	130	1.34456	170	1.49964	210	1.66358
91	1.20162	131	1.34832	171	1.50364	211	1.66777
92	1.20518	132	1.35212	172	1.50765	212	1.67196
93	1.20875	133	1.35592	173	1.51165	213	1.67620
94	1.21231	134	1.35972	174	1.51566	214	1.68044
95	1.21587	135	1.36352	175	1.51966	215	1.68469
96	1.21947	136	1.36733	176	1.52367	216	1.68893
97	1.22307	137	1.37113	177	1.52773	217	1.69317
98	1.22667	138	1.37493	178	1.53178	218	1.69741
99	1.23027	139	1.37873	179	1.53584	219	1.70166
100	1.23388	140	1.38253	180	1.53989	220	1.70590
101	1.23748	141	1.38637	181	1.54395	221	1.71014
102	1.24108	142	1.39020	182	1.54800	222	1.71443
103	1.24468	143	1.39404	183	1.55205	223	1.71872
104	1.24828	144	1.39788	184	1.55611	224	1.72301
105	1.25193	145	1.40171	185	1.56017	225	1.72730
106	1.25558	146	1.40555	186	1.56426	226	1.73159
107	1.25923	147	1.40939	187	1.56836	227	1.73588
108	1.26288	148	1.41322	188	1.57245	228	1.74017
109	1.26653	149	1.41706	189	1.57655	229	1.74446
110	1.27018	150	1.42095	190	1.58064	230	1.74875
111	1.27383	151	1.42484	191	1.58474	231	1.75309
112	1.27748	152	1.42873	192	1.58883	232	1.75744
113	1.28113	153	1.43262	193	1.59293	233	1.76178
114	1.28484	154	1.43651	194	1.59702	234	1.76613
115	1.28854	155	1.44040	195	1.60116	235	1.77047
116	1.29225	156	1.44429	196	1.60530	236	1.77482
117	1.29595	157	1.44818	197	1.60943	237	1.77916
118	1.29966	158	1.45207	198	1.61357	238	1.78351
119	1.30336	159	1.45602	199	1.61771	239	1.78785

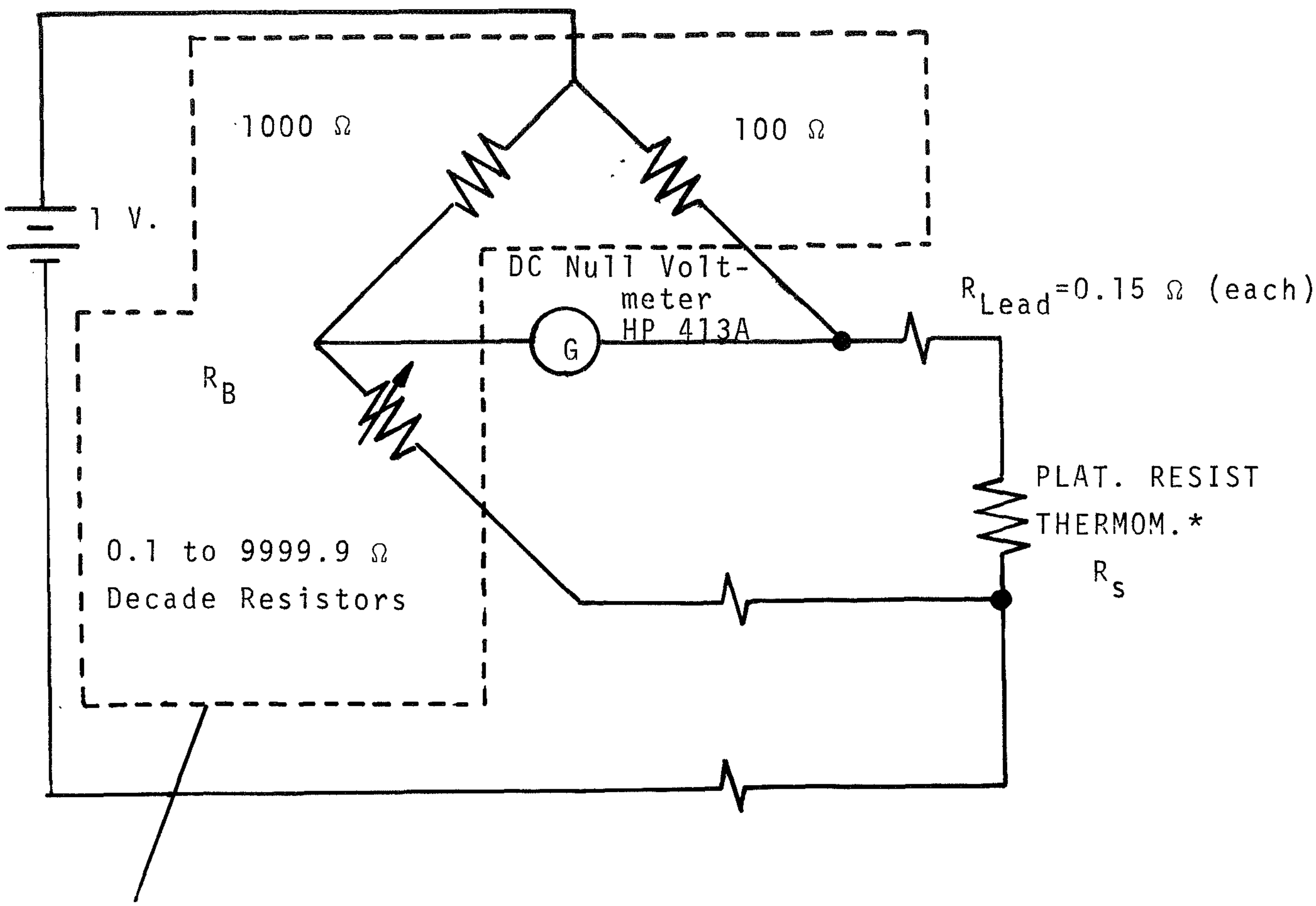
NOTE: $R_T = R_{32} \times$ RATIO; WHERE R_T IS RESISTANCE AT ANY TEMPERATURE T, AND R_{32} IS RESISTANCE AT 32°F.

MINCO PRODUCTS, INC. MINNEAPOLIS, MINN.	RESISTANCE RATIO TABLE FOR CHEMICALLY-PURE NICKEL RESISTANCE THERMOMETERS	NO. 6
PREP'D. BY [illegible]		
CHK'D. BY [illegible]	FIG. 4 PG. 2	PAGE 3 OF 6
APPR'D. BY [illegible]		



60 CYCLE FILTER AS SHOWN ABOVE

Fig. 5 SCHEMATIC OF TYPICAL BRIDGE CIRCUIT AND 60 CYCLE FILTER



Included in Leeds & Northrup
#4725 Bridge

NOTE: The "3 lead sensor" is complicated by the requirement that the resistors on the left side are 10 times value of those on right side of bridge. At 1 volt input voltmeter can detect 0.1 ohm change in R_B.

$$\frac{R_B}{10 \times 471.86} = C = T(°F)$$

from Fig. 7 interpolated as required.

FIGURE. 6 BRIDGE CIRCUIT FOR PLATINUM REFERENCE THERMOMETER

*MINCO Prod. Co., #31A, Factory Calibration 469.76Ω at 32.00°F. M.I.T. Calibration equivalent to 471.86Ω

T (°F.)	RATIO	T (°F.)	RATIO
-20	.88438	109	1.16939
-10	.90670	110	1.17158
0	.92898	111	1.17377
+10	.95121	112	1.17595
+15	.96232	113	1.17813
+20	.97341	114	1.18032
+21	.97562	115	1.18250
32	1.00000	120	1.19341
33	1.00221	125	1.20433
34	1.00442	130	1.21521
35	1.00663	135	1.22610
40	1.01769	140	1.23698
45	1.02874	141	1.23915
50	1.03979	142	1.24132
55	1.05082	143	1.24350
60	1.06184	144	1.24567
65	1.07286	145	1.24784
66	1.07506	146	1.25001
67	1.07726	147	1.25218
68	1.07946	148	1.25436
69	1.08166	149	1.25653
70	1.08386	150	1.25870
71	1.08606	151	1.26087
72	1.08826	152	1.26304
73	1.09046	153	1.26522
74	1.09266	154	1.26739
75	1.09486	155	1.26956
80	1.10586	156	1.27173
85	1.11683	157	1.27389
90	1.12780	158	1.27606
95	1.13875	159	1.27823
100	1.14970	160	1.28039
105	1.16064	165	1.29122
106	1.16283	170	1.30205
107	1.16501		
108	1.16720		

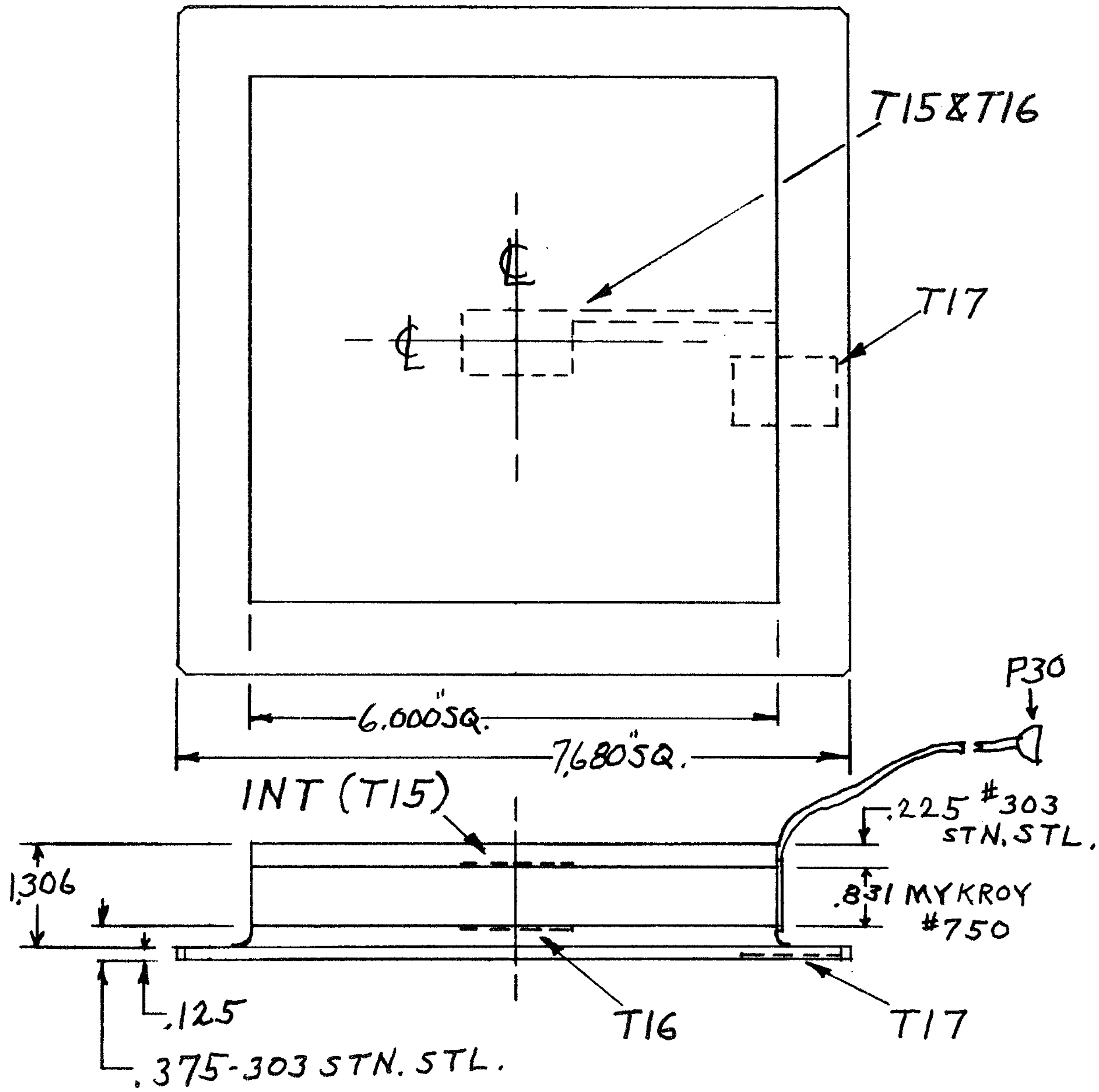
FIG. 7. Condensed "Resistance Ratio Table for Strain-free Platinum Resistance Thermometers" Table No.2-11 Pages

From: Minco Products Co., Minneapolis, Minnesota. Dated Oct.31, 1966

A-7-157

REF. D-7-116

MEASURED AIR GAP SMALL SIDE .025"
LARGE SIDE .034"
(SEE D-7-118A)



SEE NASA-ERC DWG. F-69-10

ALL 3 SENSORS RdF BN200
200 Ω C.P.NICKLE
(RECESSED .015" DP. IN STN. STL.)
BLANCHARD GRIND PER A-7-150
4 SURFACES

FIG. 8. DWG. A-7-157

A-1-14.1

EXPERIMENTAL ASTRONOMY LABORATORY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

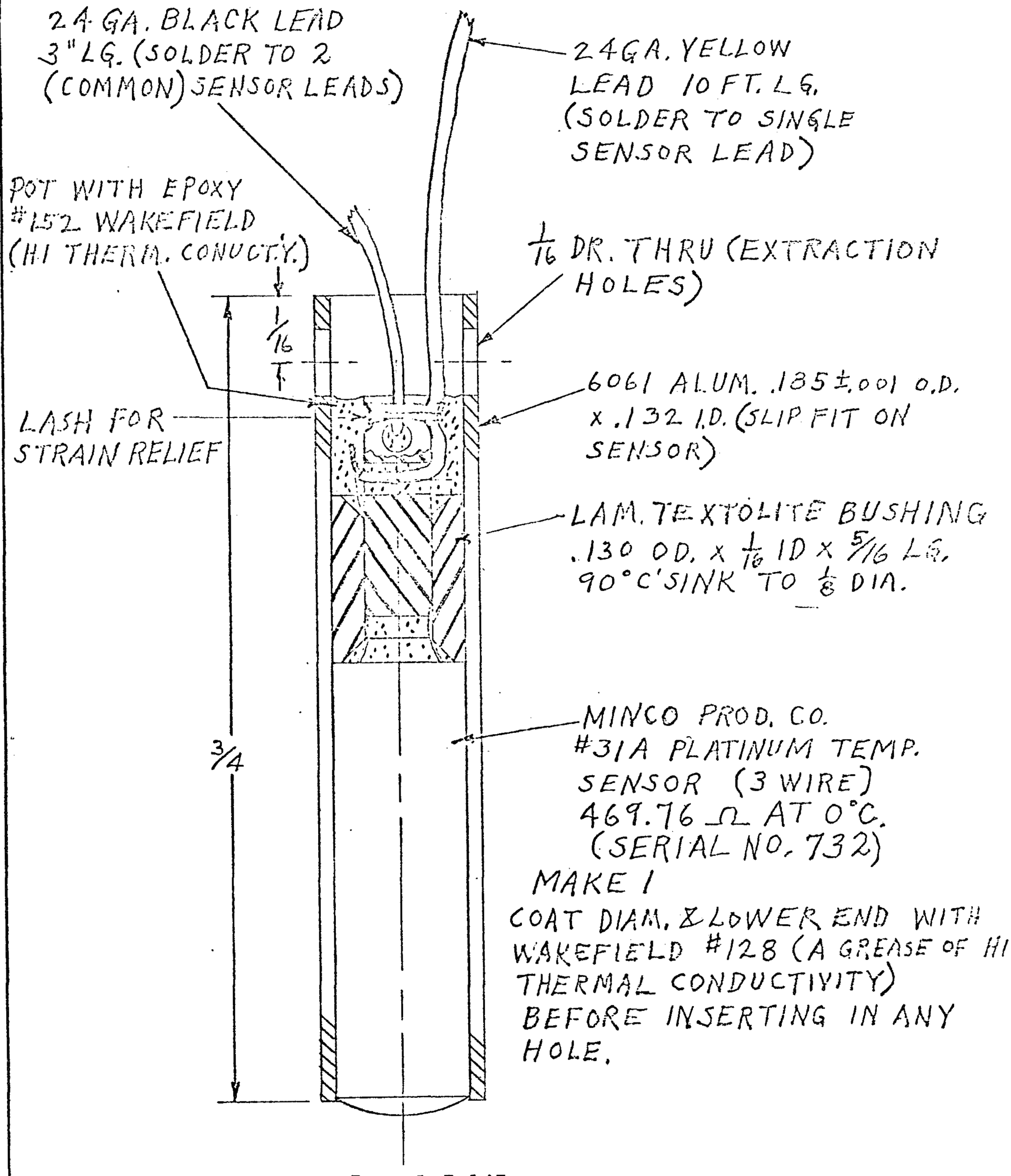
PREPARED J. J. Egan

DATE Nov. 6, '69

71511

SHEET OF

REF. C-7-146



Dwg. A-7-147

A-7-137A

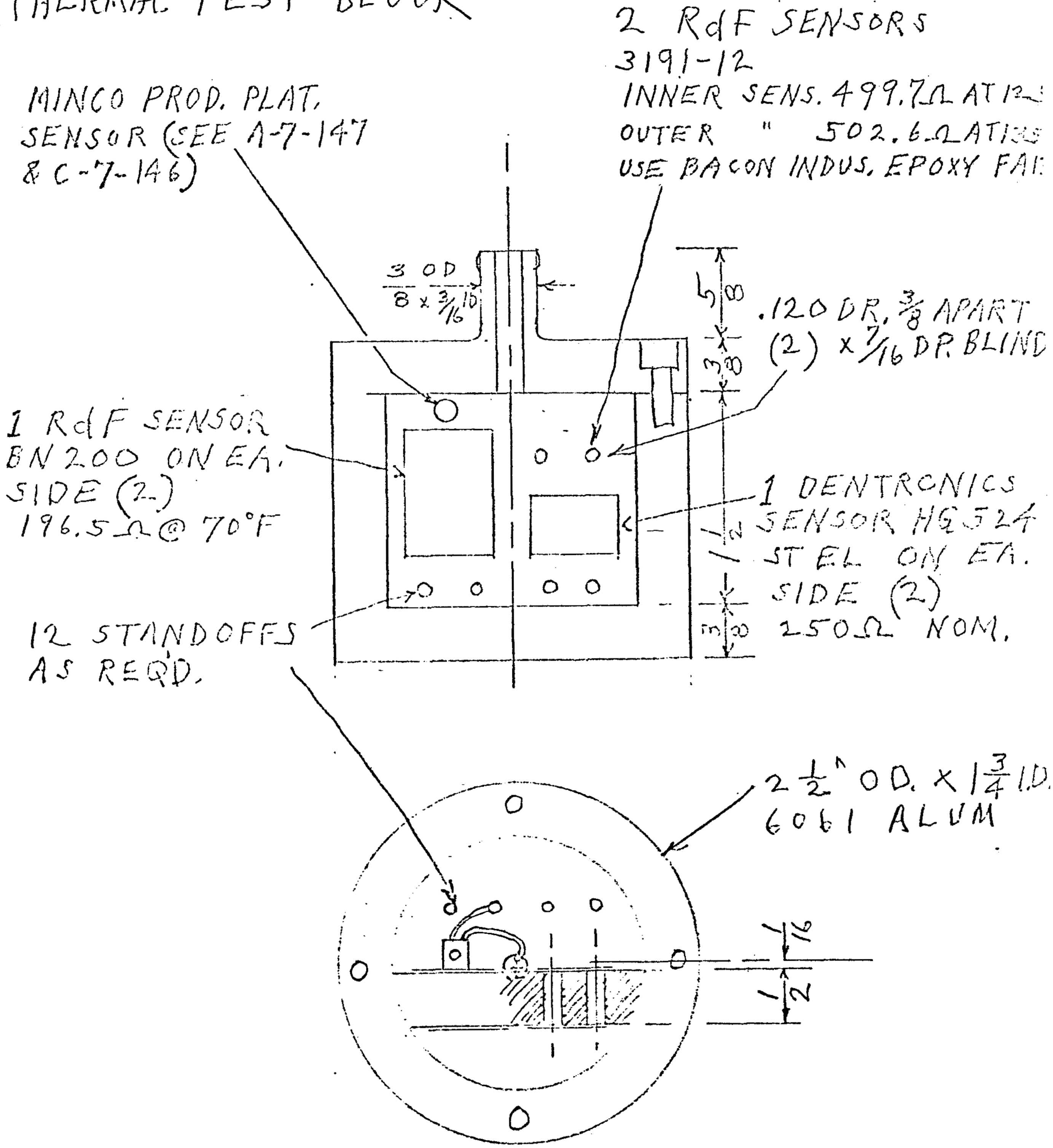
EXPERIMENTAL ASTRONOMY LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PREPARED J. T. Egan
DATE Oct 1, '69

71511

SHEET OF

THERMAL TEST BLOCK



SEE WIRING DIAGR. ON C-7-146

Dwg. A-7-137A

SENSOR DEVIATION FROM LINEARITY
RdF PURE NICKLE

8-21-69
ALAN J. SLOBODNIK
MIT - MSL

T (°F)	COUNTS	ERROR	T(°F)	COUNTS	ERROR
160.	16022.	+.22°F	80.	7993.	- 7
155.	15498.	- 2	75.	7514.	+14
→ 150.	15000.	0	→ 70.	7000.	0
145.	14499	-.01°F	65.	6516.	+16
140.	13995	- 5	60.	6028.	+28
135.	13488.	-12	55.	5538.	+38
130.	13008.	+ 8	50.	5046.	+46
125.	12496.	- 4	45.	4550.	+50
120.	12010.	+10	40.	4085.	+85
115.	11522.	+22	35.	3618.	+118
→ 110.	11000.	0	30.	3148.	+148
105.	10506.	+6	25.	2676.	+176
100.	10009.	+9	20.	2202.	+202
95.	9510	+10	15.	1725.	+ 225
90.	9007.	+7	10.	1245.	+ 245
85.	8502.	+2	5.	763.	+263
			0.	278.	+ 2.78°F

SENSOR DEVIATION FROM LINEARITY

250 Ω DENTRONICS NICKLE A

8-22-69

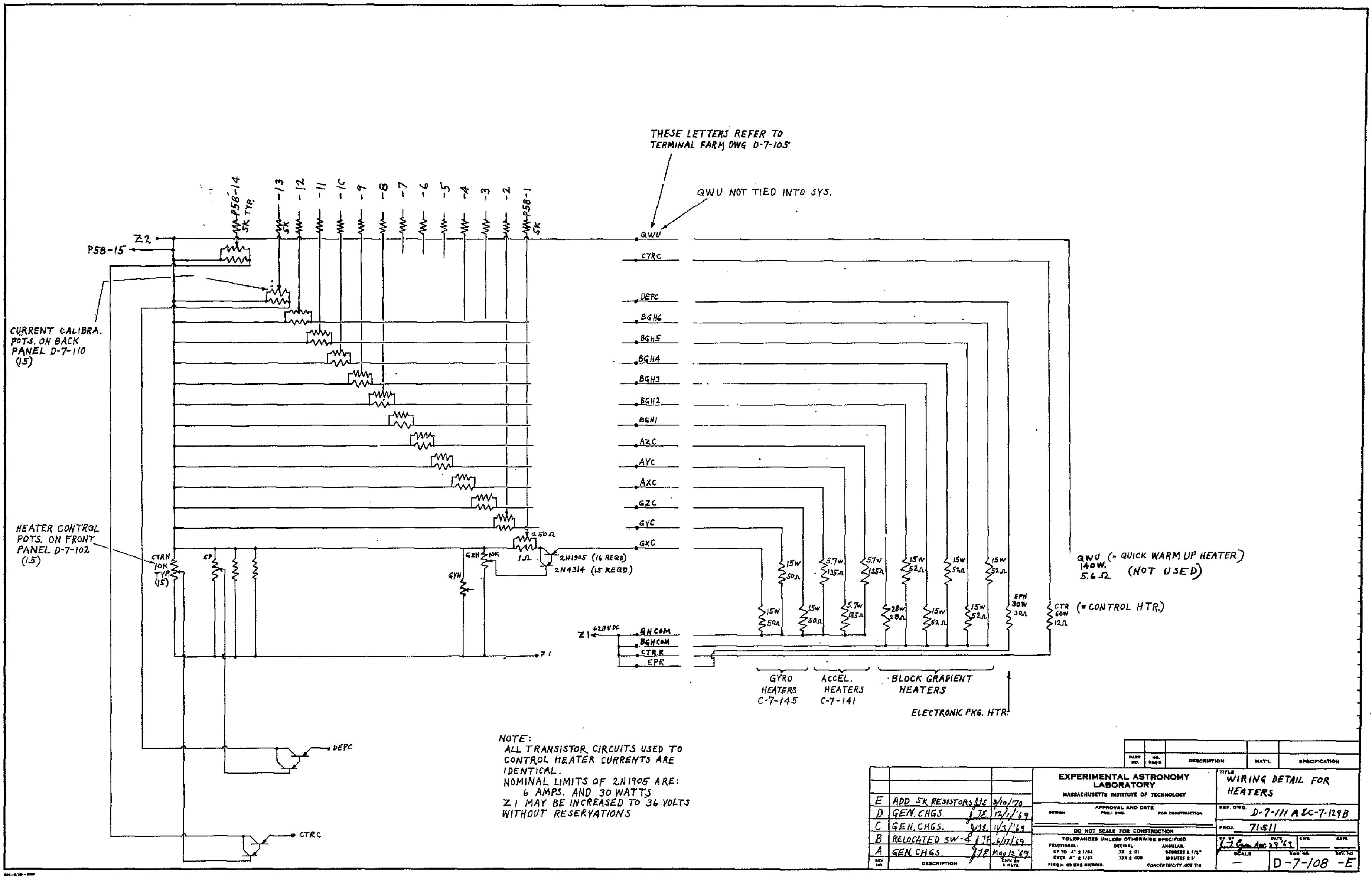
ALAN J. SLOBODNIK

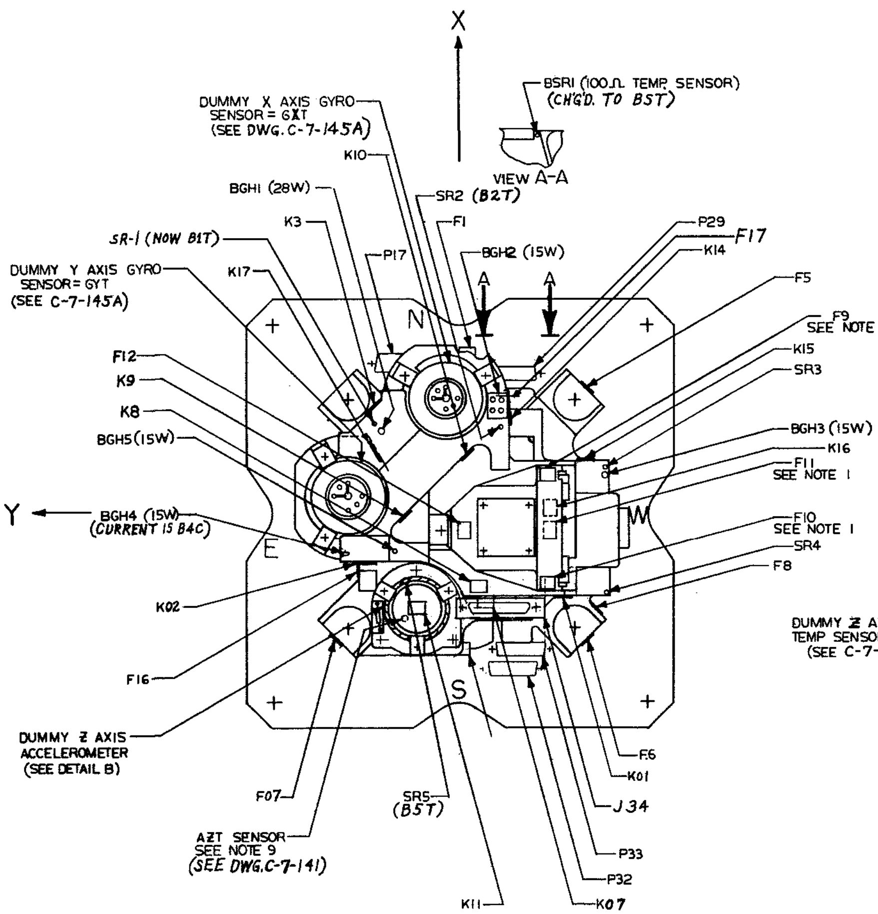
MIT-MSL

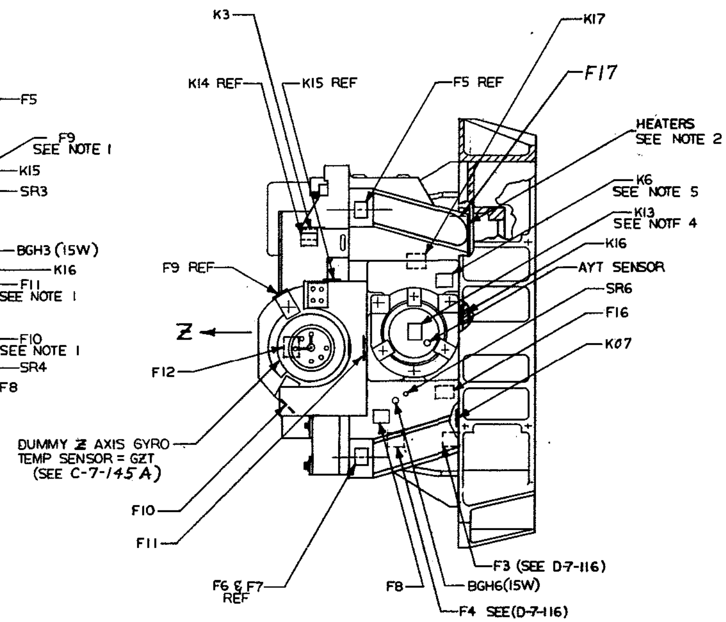
T(°F)	COUNTS	ERROR
160.	16042.	+.42 °F
→ 150.	15000	0
140.	14025.	+25
130.	13040.	+40
120.	12005.	+5
→ 110.	11000.	0
100.	9984.	-16
90.	8999.	-1
80.	8004.	+4
→ 70.	7000.	0
60.	6027.	+27
50.	5046.	+46
40.	4054.	+54
30.	3097.	+97
20.	2131.	+131
10.	1156.	+156
0.	171.	+1.71 °F.

Appendix II

Figures


THESE LETTERS REFER TO TERMINAL FARM DWG D-7-105
QWU NOT TIED INTO SYS.
P58-14 5K TYP.
P58-1 5K
P58-15
Z2
CURRENT CALIBRA. POTS. ON BACK PANEL D-7-110 (15)
HEATER CONTROL POTS. ON FRONT PANEL D-7-102 (15)
CTRH 10K TYP. (15)
EP
GYH
GXH 10K
250Ω
1Ω
2N1905 (16 REQD)
2N4314 (15 REQD.)
QWU
CTRC
DEPC
BGH6
BGH5
BGH4
BGH3
BGH2
BGH1
AZC
AYC
AXC
GZC
GYC
GXC
Z1 +28 VDC
GH COM
BGH COM
CTR R
EPR
QWU (= QUICK WARM UP HEATER) 140W. 5.6Ω (NOT USED)
CTR 60W 12Ω (= CONTROL HTR.)
EPH 30W 30Ω
GYRO HEATERS C-7-145
ACCEL. HEATERS C-7-141
BLOCK GRADIENT HEATERS
ELECTRONIC PKG. HTR.
NOTE:
ALL TRANSISTOR CIRCUITS USED TO CONTROL HEATER CURRENTS ARE IDENTICAL.
NOMINAL LIMITS OF 2N1905 ARE: 6 AMPS. AND 30 WATTS
Z1 MAY BE INCREASED TO 36 VOLTS WITHOUT RESERVATIONS
E ADD 5K RESISTORS 3/10/'70
D GEN. CHGS. 12/1/'69
C GEN. CHGS. 11/3/'69
B RELOCATED SW-4 6/17/'69
A GEN. CHGS. May 12 '69
EXPERIMENTAL ASTRONOMY LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DO NOT SCALE FOR CONSTRUCTION
WIRING DETAIL FOR HEATERS
REF. DWG. D-7-111 & C-7-129B
PROJ. 71811
D-7-108 -E





NOTES:

1. F11, F10, AND F9 ARE 120° APART ON GYRO MOUNTING FRAME. THIS FRAME AND ITS DUMMY GYRO MAY BE MOUNTED IN ANY 1 OF 3 POSITIONS.
2. QUICK WARM UP AND CONTROL HEATERS (140W AND 60W AT 28V) IN BLANKET (HONEYWELL DWG. D34003344).
3. ~~ACCELEROMETER ADAPTER WITH F13, F14 AND F15 MAY BE MOUNTED IN ANY 1 OF 3 POSITIONS.~~
4. ~~K11, K12, AND K13 APPEAR AT BOTTOM OF EACH ACCELEROMETER WELL. K12 DOESN'T APPEAR IN ANY VIEW ON THIS DRAWING~~
5. ~~K4, K5, AND K6 ARE ON GYRO BLOCK NEAR ACCELEROMETER MOUNTING FEET.~~
6. T-- TEMPERATURE SENSORS USE PURE NICKLE AS A RESISTIVE ELEMENT AND MAY BE IDENTIFIED AS FOLLOWS:

   T — IS "Rd F" MODEL BN-200 OR PN-200 SENSOR WITH A NORMINAL RESISTANCE OF 200Ω AT 70°F (SHOWN ON D-7-116 AND D-7-117 ONLY) QTY 17

CON'T

6. F&K - ARE "DENTRONICS" SENSORS HG-524 ST EL 250Ω AT 70°F. THESE SENSORS ARE TO BE FIRMLY ATTACHED WITH EASTMAN CEMENT NO. 910. QTY- F(17); K(16) F1,2,3, AND 4 ARE SHOWN ON BASE D-7-116

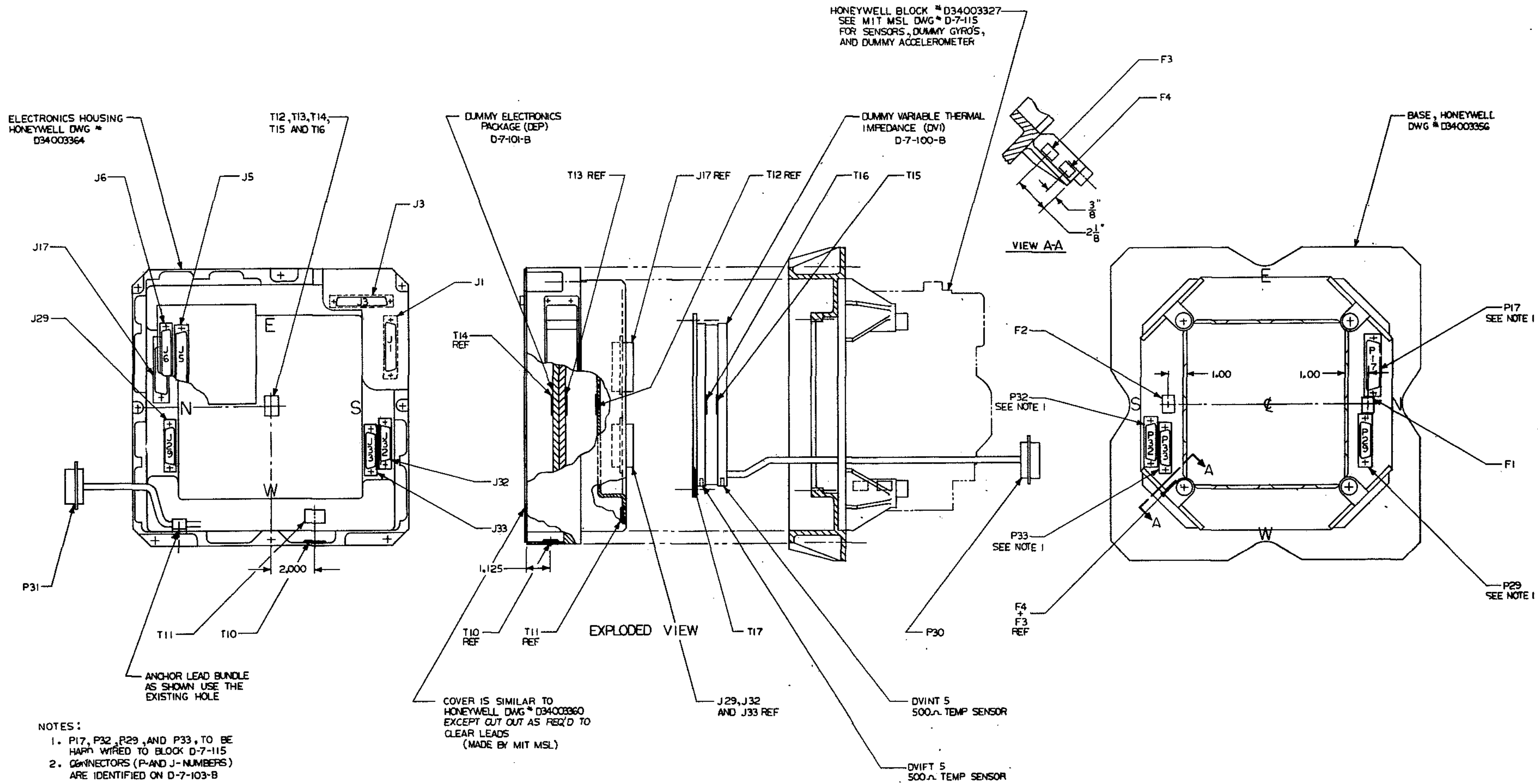
   GXT - ETC SEE DETAILS "A" AND "B" QTY 6

   BSR-1-UNKNOWN MFR 1000Ω BOBBIN TYPE QTY-1 *(NOW CALLED BST)*

   SR - UNKNOWN MFR 1400Ω BOBBIN TYPE. THESE SENSORS ARE MOUNTED IN THE MAIN GYRO BLOCK (HONEYWELL DWG D34003348 PG.3 HOLES MARKED "B") QTY-6 (#7 IS FOR ABOVE BSR-1) *(SR1 NOW CALLED B1T, ETC.)*

7. AFTER MOUNTING ALL SENSORS THE ABOVE BLOCK IS TO BE OVEN HEATED FOR ONE HOUR AT 160°F, AND WHILE STILL HOT, ALL F AND K SENSORS ARE TO BE COVERED WITH DOW CORNING DC-4 SILICONE GREASE
8. REMOVE PORRO PRISM AND INSTALL J34. SEE DWG'S D-7-103B AND D-7-121
9. THE AXT SENSOR APPEARS UNDER THIS ACCELEROMETER AND IS NOT SHOWN IN THIS VIEW.

Part of D-7-115



NOTES:

1. P17, P32, P29, AND P33, TO BE HARD WIRED TO BLOCK D-7-115
2. CONNECTORS (P-AND J-NUMBERS) ARE IDENTIFIED ON D-7-103-B
3. J1, J3, J5 AND J6, ARE EXISTING PLUGS USED WITHOUT CHANGE (SEE D-7-103-B AND D-7-121 FOR WIRING INFORMATION)
4. ALL T-NUMBERS ARE RdF BN-200 NICKLE WIRE 200Ω TEMP. SENSORS (DIMENSIONS 9/16" X 7/8")
5. ALL F-NUMBERS ARE DENTRONICS HG-524-ST EL NICKLE FOIL 250Ω TEMP. SENSORS (DIMENSIONS 13/32" X 1/2")

PART NO.	NO. REQ'D	DESCRIPTION	MAT'L	SPECIFICATION

REV. NO.	DESCRIPTION	CH'K BY & DATE

EXPERIMENTAL ASTRONOMY LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APPROVAL AND DATE: DESIGN / PROJ. ENG. / FOR CONSTRUCTION

DO NOT SCALE FOR CONSTRUCTION

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONAL: UP TO 4" ± 1/64, OVER 4" ± 1/32
DECIMAL: .XX ± .01, .XXX ± .005
ANGULAR: DEGREES ± 1/2°, MINUTES ± 5'
FINISH: 63 RMS MICROIN.
CONCENTRICITY .002 TIR

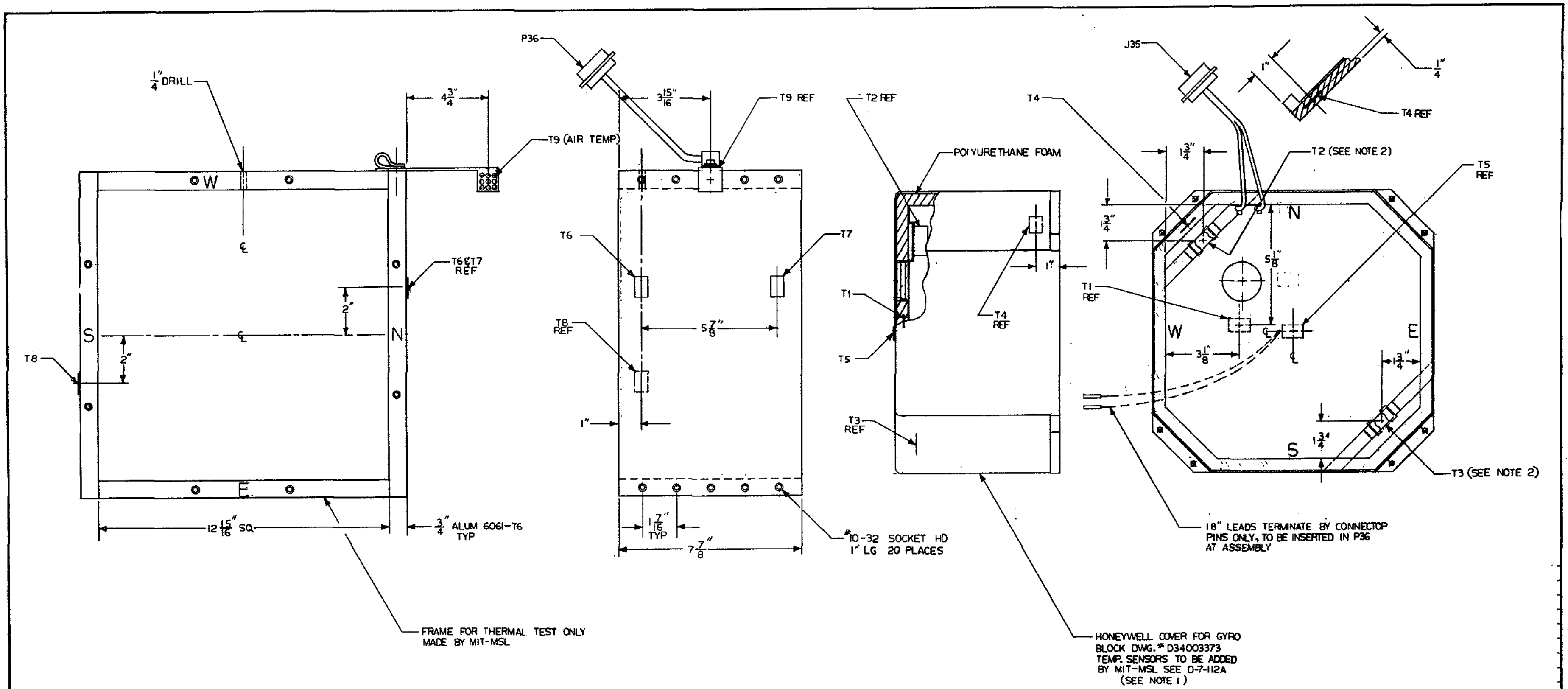
TITLE: SUB-ASSEMBLY
STRAPDOWN INERTIAL SENSING UNIT

REF. DWG. D-7-

PROJ. 71511

DR. BY [signature] DATE 5-2-69 | CH'K | DATE

SCALE 1/2 | DWG. NO. D-7-116 | REV. NO. -



NOTES:

1. ALL TEMPERATURE SENSORS ARE RdF BN-200 (200Ω NICKLE WIRE)
2. T2 AND T3 ARE TEMPERATURE SENSORS FOR AIR WHICH SURROUNDS THE GYRO BLOCK

PART NO.	NO. REQ'D	DESCRIPTION	MAT'L	SPECIFICATION

REV. NO.	DESCRIPTION	CH'K BY & DATE

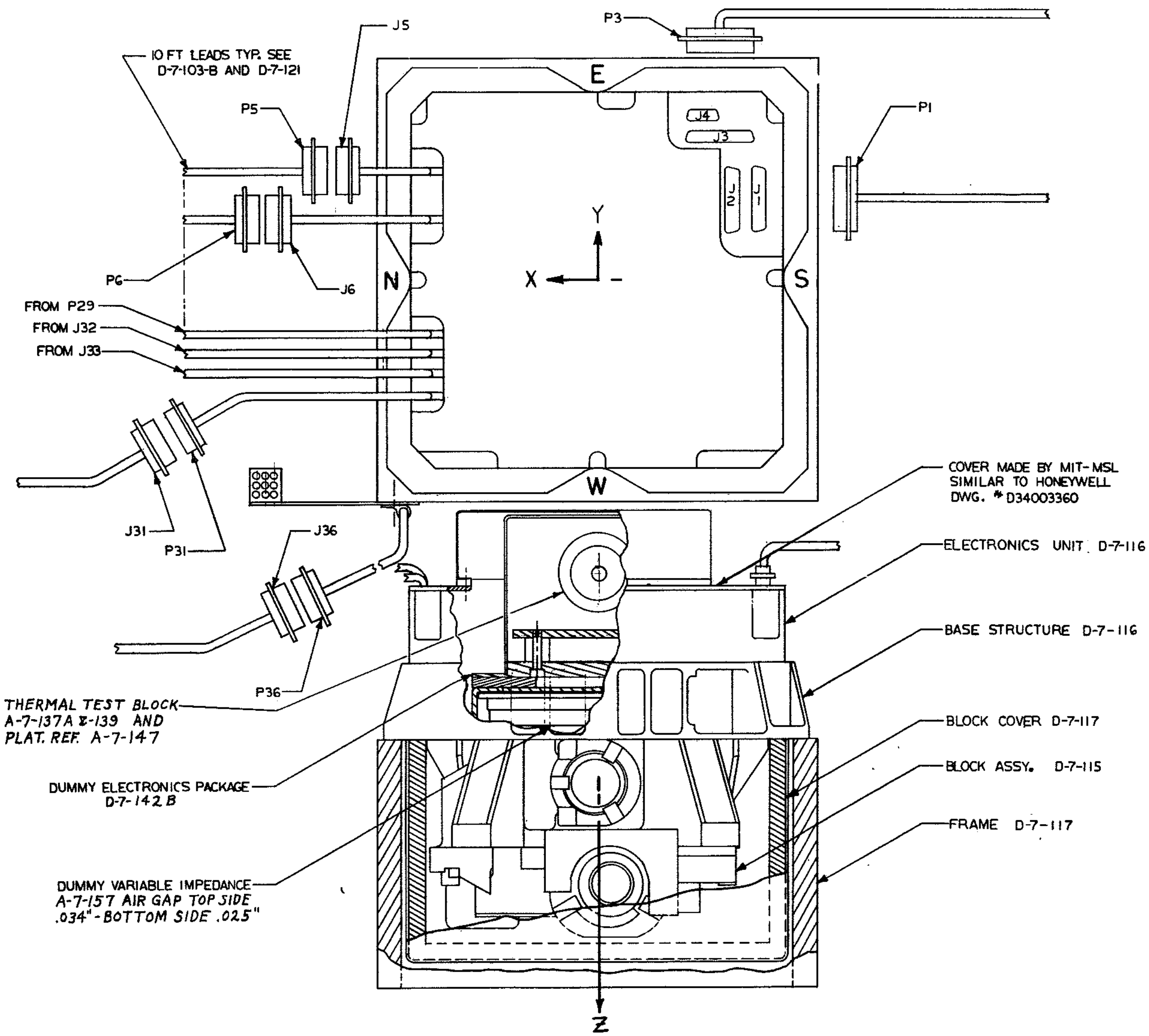
EXPERIMENTAL ASTRONOMY LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APPROVAL AND DATE: DESIGN / PROJ. ENG. / FOR CONSTRUCTION

DO NOT SCALE FOR CONSTRUCTION

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONAL: UP TO 4" ± 1/64; OVER 4" ± 1/32
DECIMAL: .XX ± .01; .XXX ± .005
ANGULAR: DEGREES ± 1/2°; MINUTES ± 5'
FINISH: 63 RMS MICROIN. CONCENTRICITY .002 TIR

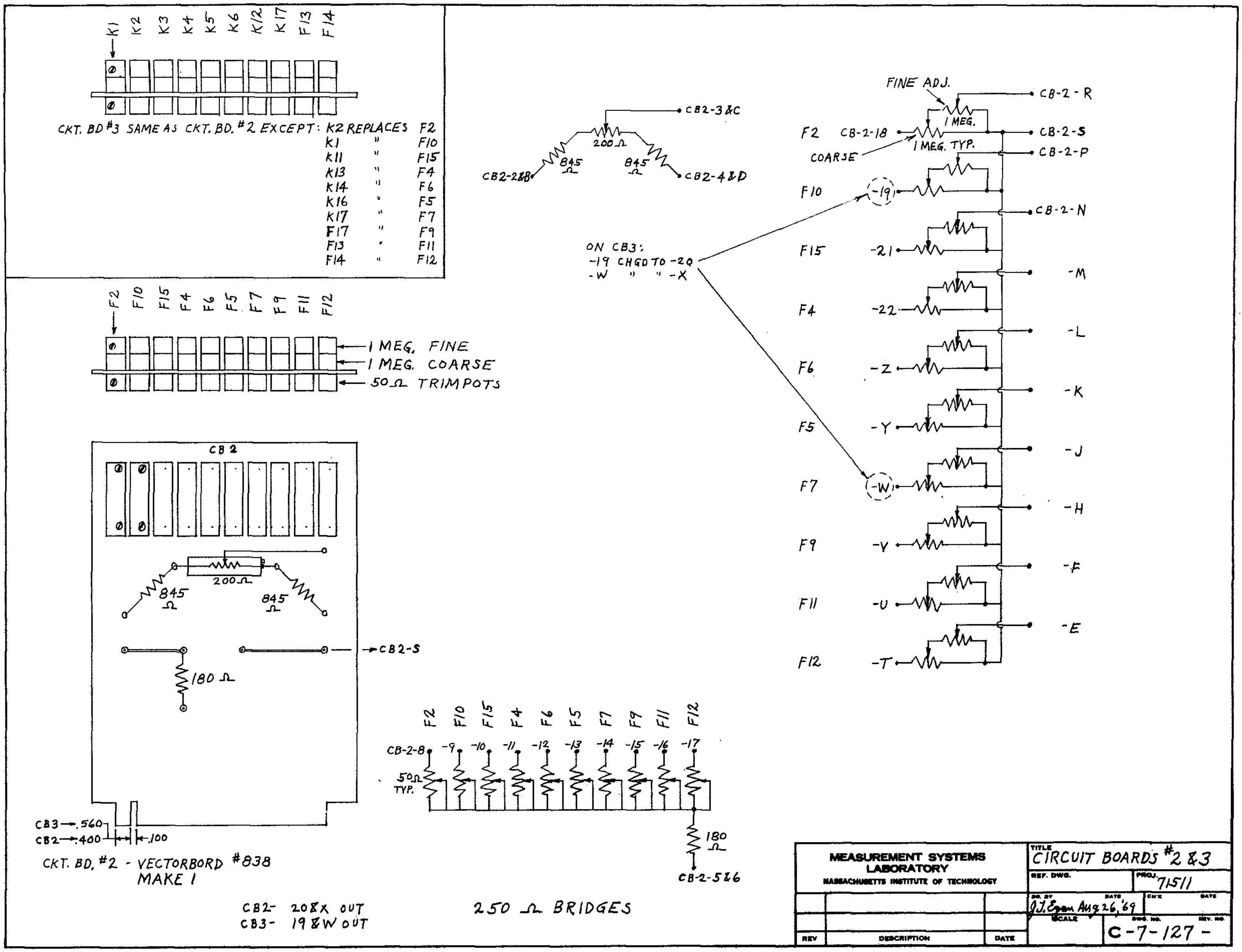
TITLE: SENSOR MOUNTING FRAME AND COVER BLOCK
REF. DWG.
PROJ. 71511
DR. BY R.T. Boyle DATE 4-21-69 CH'K DATE
SCALE 1/2 DWG. NO. D-7-117 REV. NO. -

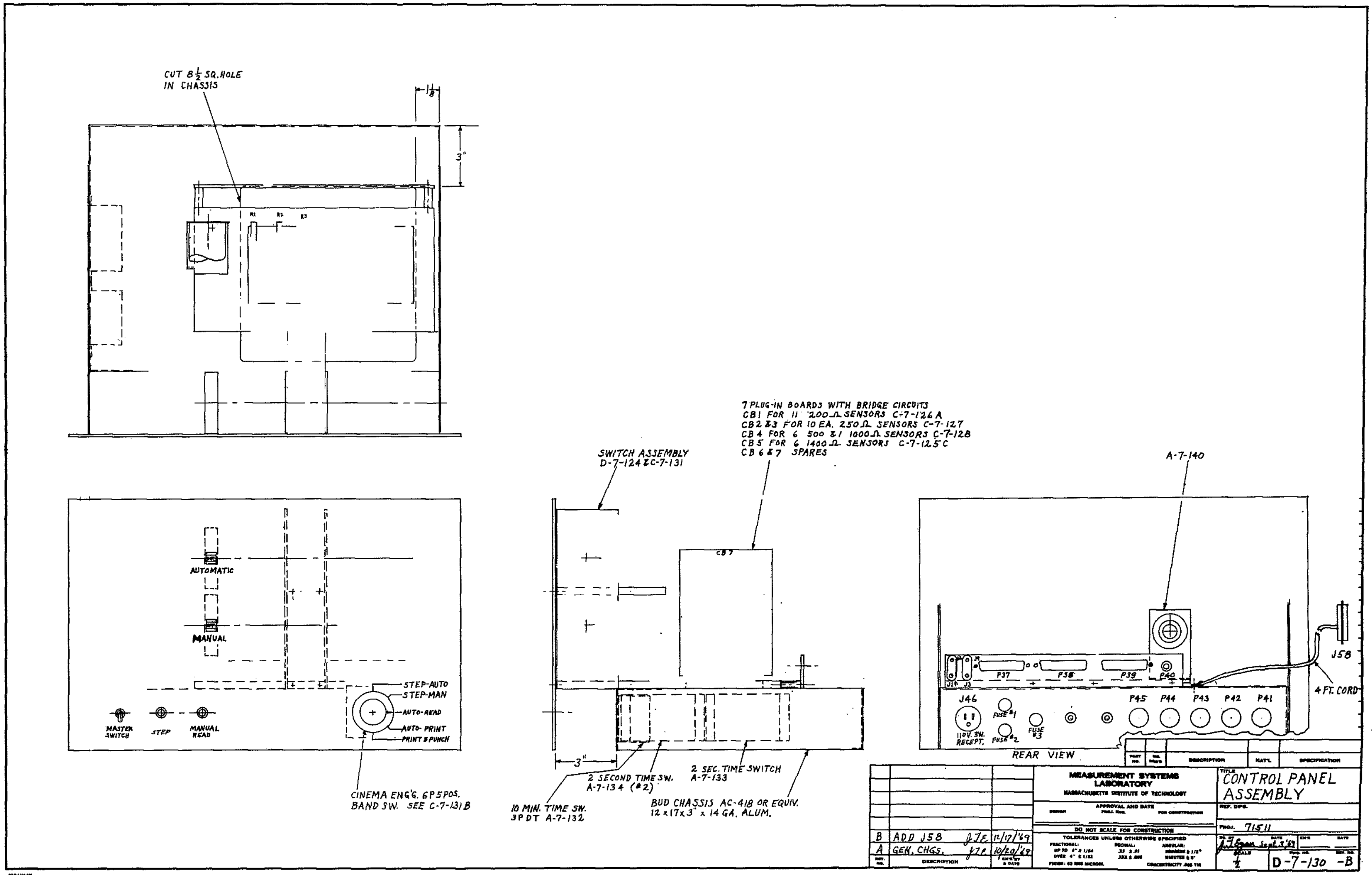


NOTES:

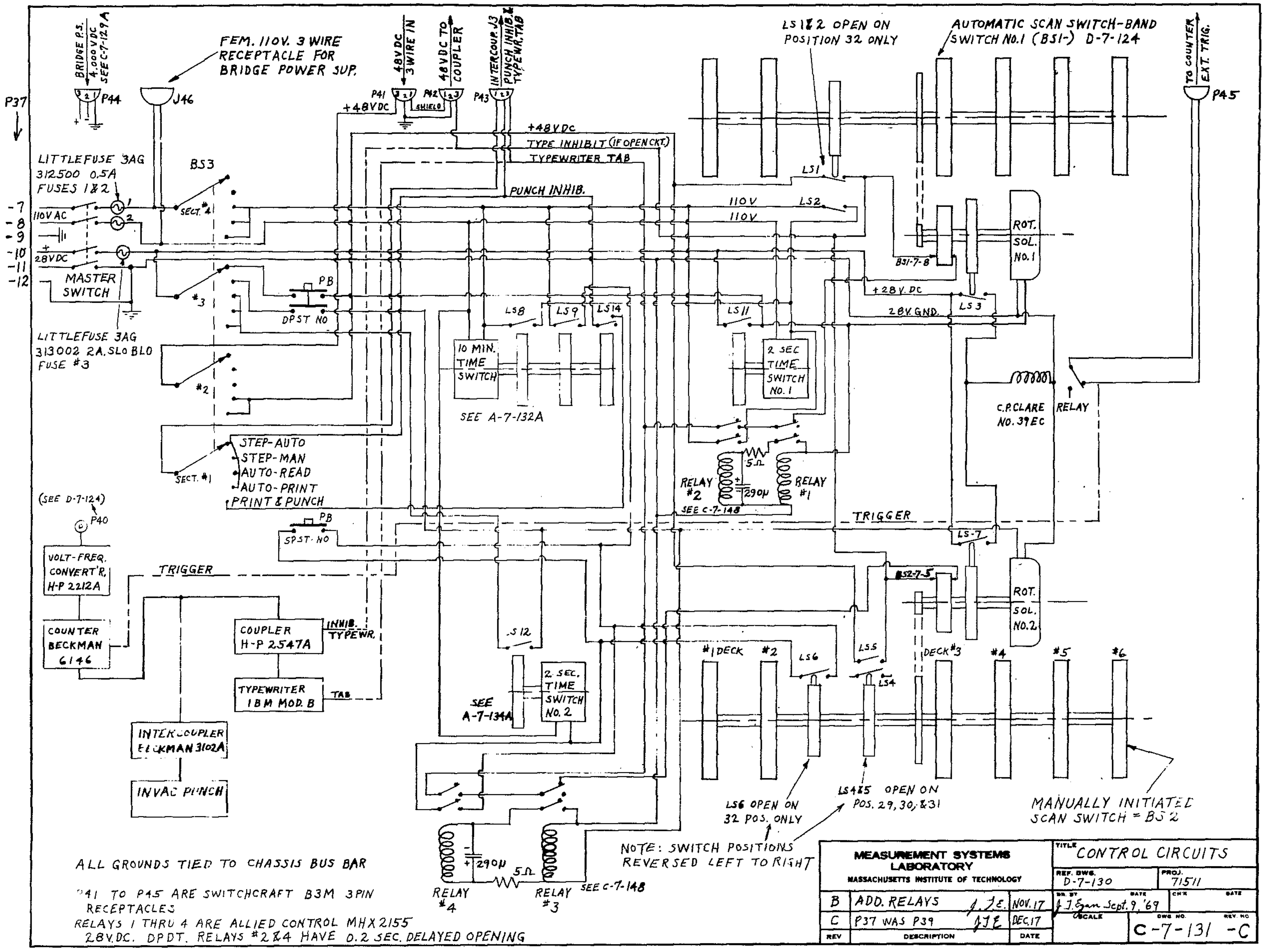
1. THIS ASSEMBLY SHOWS A BASIC HONEYWELL STRAPDOWN INERTIAL SENSING UNIT # D34003310 AS SET UP FOR THERMAL STUDIES. THE ELECTRONICS COMPONENTS HAVE BEEN REPLACED WITH A DUMMY ELECTRONICS PACKAGE, (D-7-142-B) AND THE PASSIVE VARIABLE THERMAL IMPEDANCE DEVICE HAS BEEN REPLACED WITH A FIXED IMPEDANCE BLOCK (DWG A-7-157). THE ELECTRONICS PKG. HAS A CONTROLABLE HEATER. SOME 37 TEMPERATURE SENSORS HAVE BEEN ADDED FOR THIS STUDY. THE MAJOR COMPONENTS HAVE NOT BEEN MUTILATED IN ANY WAY.

Part of Dwg. D-7-118A

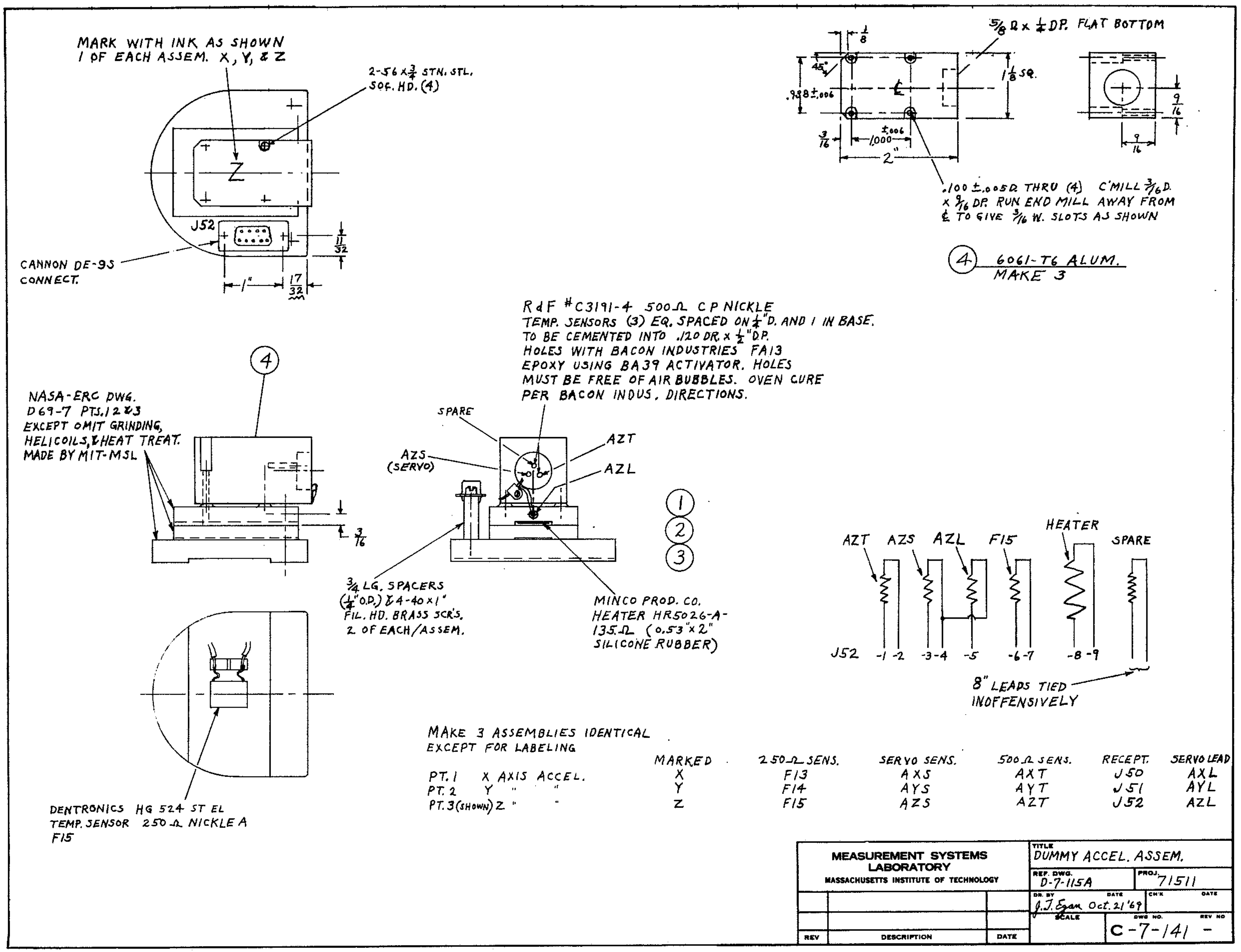

K1 K2 K3 K4 K5 K6 K12 K17 F13 F14
CKT. BD #3 SAME AS CKT. BD. #2 EXCEPT: K2 REPLACES F2
K1 " F10
K11 " F15
K13 " F4
K14 " F6
K16 " F5
K17 " F7
F17 " F9
F13 " F11
F14 " F12
F2 F10 F15 F4 F6 F5 F7 F9 F11 F12
1 MEG. FINE
1 MEG. COARSE
50 Ω TRIMPOTS
CB 2
200 Ω
845 Ω
845 Ω
180 Ω
CB2-S
CB3 → .560
CB2 → .400
.100
CKT. BD. #2 - VECTORBORD #838
MAKE 1
CB2- 208X OUT
CB3- 198W OUT
CB2-3&C
200 Ω
845 Ω
845 Ω
CB2-2&B
CB2-4&D
ON CB3:
-19 CHGD TO -20
-W " " -X
FINE ADJ.
CB-2-R
1 MEG.
F2 CB-2-18
1 MEG. TYP.
COARSE
CB-2-S
CB-2-P
F10 -19
CB-2-N
F15 -21
-M
F4 -22
-L
F6 -Z
-K
F5 -Y
-J
F7 -W
-H
F9 -V
-F
F11 -U
-E
F12 -T
F2 F10 F15 F4 F6 F5 F7 F9 F11 F12
CB-2-8 -9 -10 -11 -12 -13 -14 -15 -16 -17
50Ω TYP.
180 Ω
CB-2-5&6
250 Ω BRIDGES
MEASUREMENT SYSTEMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
TITLE CIRCUIT BOARDS #2 &3
REF. DWG.
PROJ. 71511
DR. BY J.J. Egan DATE Aug 26, '69
CH'K DATE
SCALE
DWG. NO. C-7-127 -
REV. NO.
REV DESCRIPTION DATE

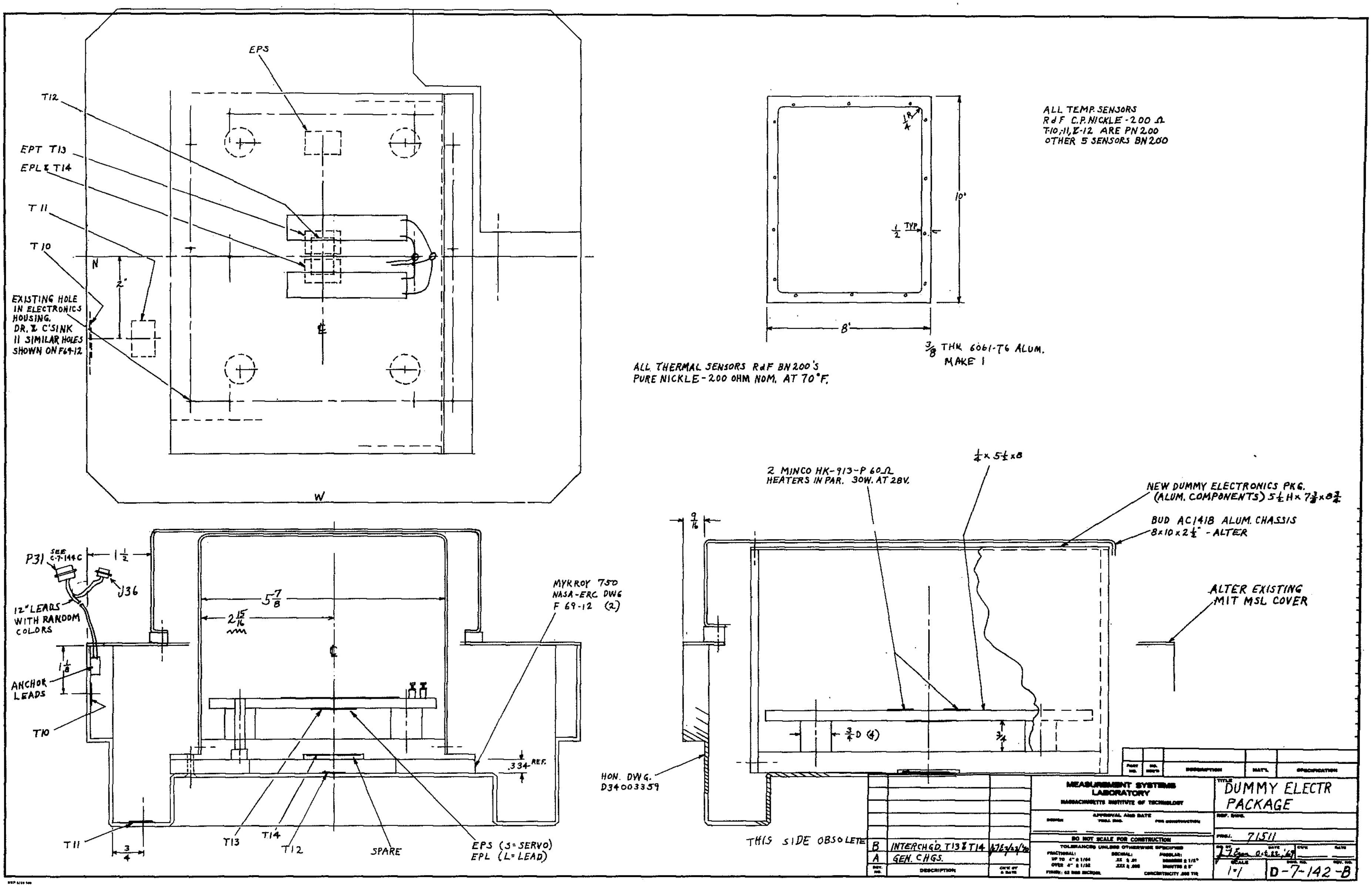


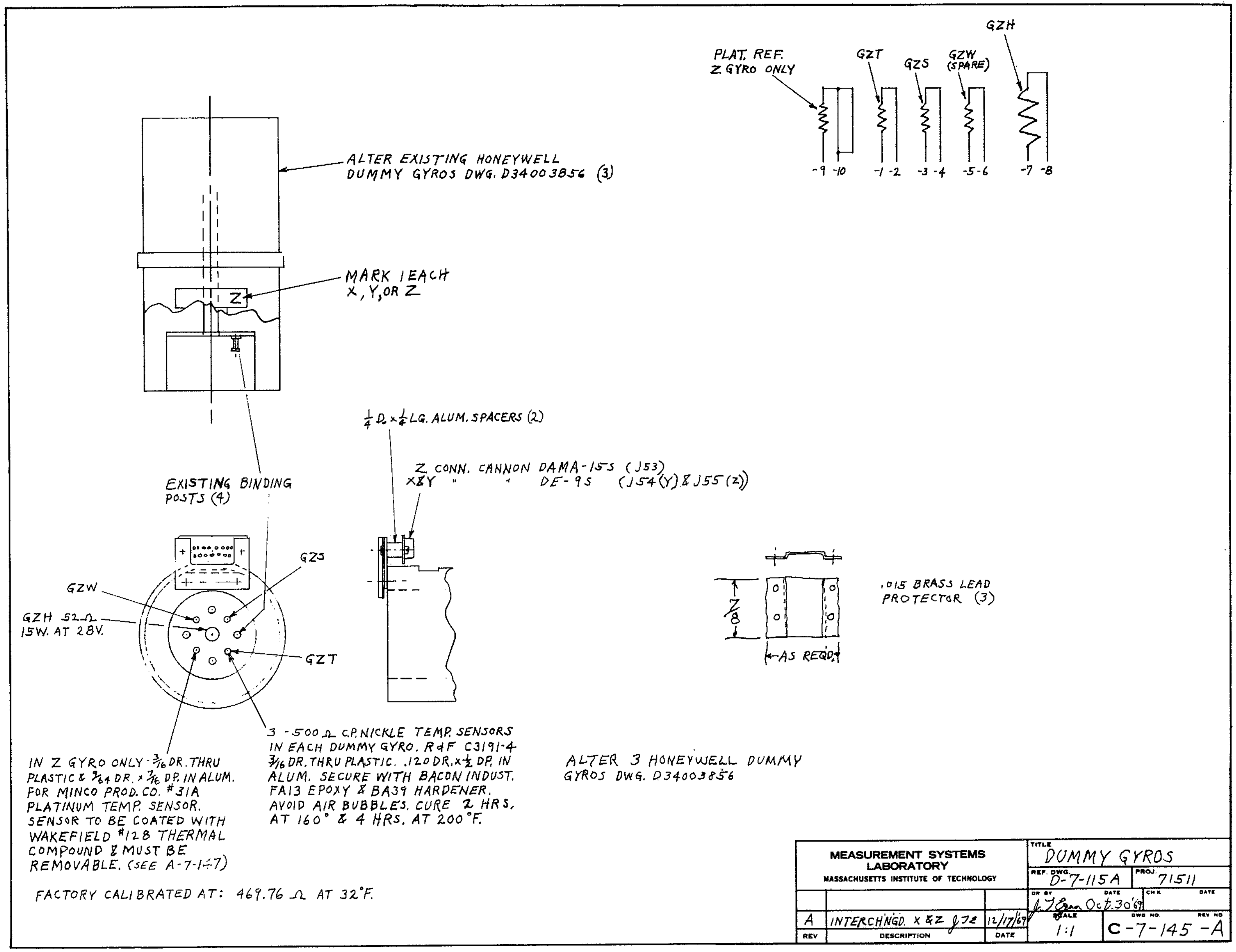
CUT 8½ SQ. HOLE IN CHASSIS
1⅛
3"
R1 R2 R3
AUTOMATIC
MANUAL
MASTER SWITCH
STEP
MANUAL READ
STEP-AUTO
STEP-MAN
AUTO-READ
AUTO-PRINT
PRINT & PUNCH
CINEMA ENG'G. 6P 5 POS. BAND SW. SEE C-7-131 B
SWITCH ASSEMBLY D-7-124 & C-7-131
7 PLUG-IN BOARDS WITH BRIDGE CIRCUITS
CB1 FOR 11 200Ω SENSORS C-7-126 A
CB2 & 3 FOR 10 EA. 250Ω SENSORS C-7-127
CB4 FOR 6 500 & 1 1000Ω SENSORS C-7-128
CB5 FOR 6 1400Ω SENSORS C-7-125 C
CB 6 & 7 SPARES
CB7
3"
10 MIN. TIME SW. 3PDT A-7-132
2 SECOND TIME SW. A-7-134 (#2)
2 SEC. TIME SWITCH A-7-133
BUD CHASSIS AC-418 OR EQUIV. 12 x 17 x 3" x 14 GA. ALUM.
A-7-140
J58
4 FT. CORD
J1 J3
P37 P38 P39 P40
J46
110V. 3W. RECEPT.
FUSE #1
FUSE #2
FUSE #3
P45 P44 P43 P42 P41
REAR VIEW
PART NO.
NO. REQ'D
DESCRIPTION
MAT'L
SPECIFICATION
MEASUREMENT SYSTEMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
APPROVAL AND DATE
DESIGN
PROJ. ENG.
FOR CONSTRUCTION
DO NOT SCALE FOR CONSTRUCTION
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONAL: UP TO 4" ± 1/64 OVER 4" ± 1/32
DECIMAL: .XX ± .01 .XXX ± .005
ANGULAR: DEGREES ± 1/2° MINUTES ± 5'
FINISH: 63 RMS MICRON.
CONCENTRICITY .005 TIR
TITLE CONTROL PANEL ASSEMBLY
REF. DWG.
PROJ. 71511
DR. BY J.T. Egan DATE Sept. 3 '69
CH'K DATE
SCALE ½
DWG. NO. D-7-130
REV. NO. -B
B ADD J58 J.T.E. 12/17/'69
A GEN. CHGS. J.T.E. 10/20/'69
REV. NO.
DESCRIPTION
CH'K BY & DATE



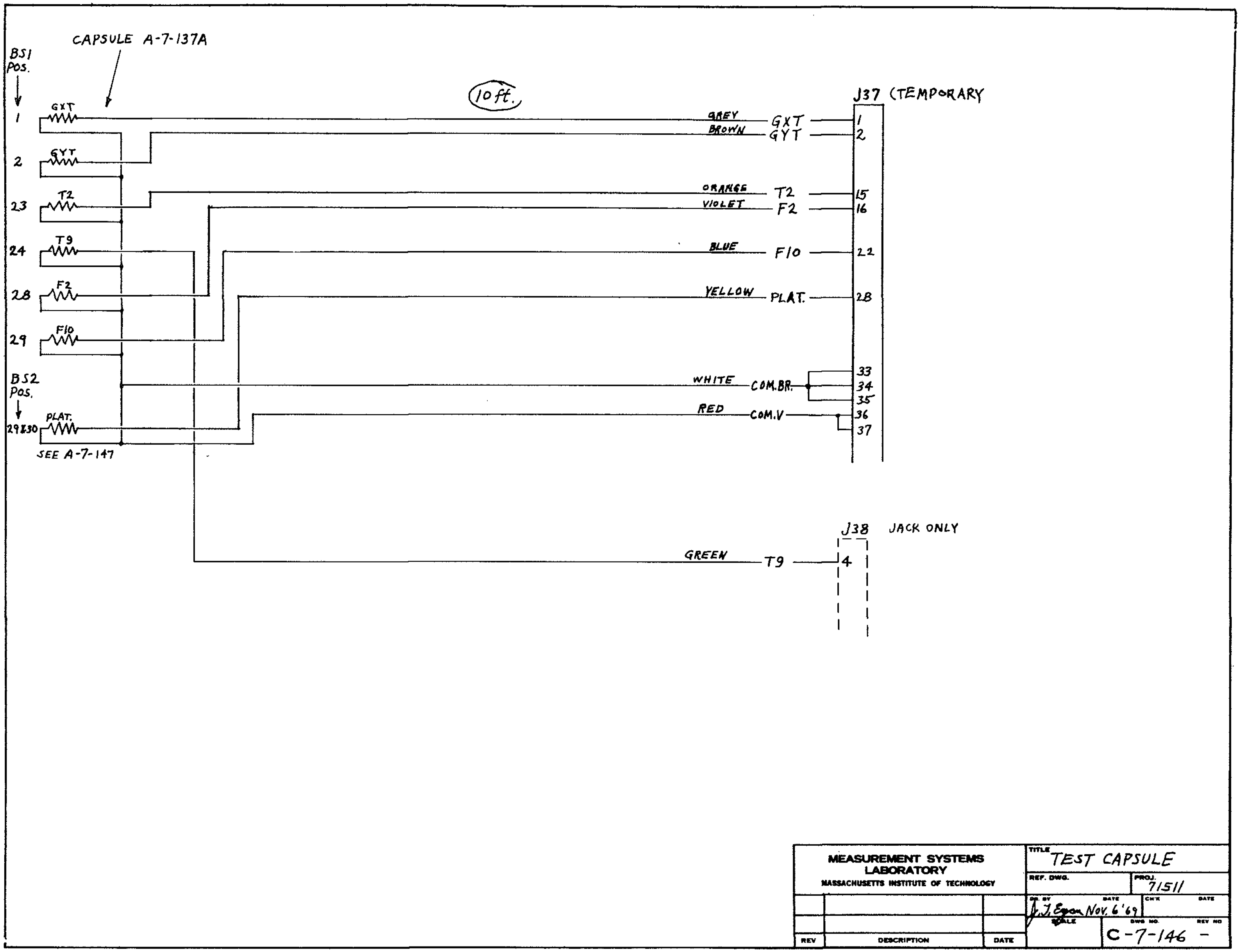
P37
BRIDGE P.S. 4,000 VDC SEE C-7-129A
P44
J46
FEM. 110V. 3 WIRE RECEPTACLE FOR BRIDGE POWER SUP.
48VDC 3 WIRE IN
48VDC TO COUPLER
INTERCOUP. J3 PUNCH INHIB. & TYPEWR. TAB
P41
P42
P43
+48VDC
SHIELD
+48VDC
TYPE INHIBIT (IF OPEN CKT.)
TYPEWRITER TAB
PUNCH INHIB.
LITTLEFUSE 3AG 312500 0.5A FUSES 1 & 2
BS3
SECT. #4
110V AC
28VDC
MASTER SWITCH
-7
-8
-9
-10
-11
-12
#3
PB
DPST NO
LITTLEFUSE 3AG 313002 2A. SLO BLO FUSE #3
#2
STEP-AUTO
STEP-MAN
AUTO-READ
AUTO-PRINT
PRINT & PUNCH
SECT. #1
PB
SPST-NO
(SEE D-7-124)
P40
VOLT-FREQ. CONVERT'R. H-P 2212A
TRIGGER
COUNTER BECKMAN 6146
COUPLER H-P 2547A
INHIB.
TYPEWR.
TYPEWRITER IBM MOD. B
TAB
INTER-COUPLER BECKMAN 3102A
INVAC PUNCH
LS 1 & 2 OPEN ON POSITION 32 ONLY
AUTOMATIC SCAN SWITCH-BAND SWITCH NO. 1 (BS1-) D-7-124
TO COUNTER EXT. TRIG.
P45
LS1
110V
LS2
110V
ROT. SOL. NO. 1
BS1-7-8
+28 V. DC
LS3
28V. GND.
LS8
LS9
LS14
LS11
10 MIN. TIME SWITCH
SEE A-7-132A
2 SEC TIME SWITCH NO. 1
C.P. CLARE NO. 39EC
RELAY
5Ω
RELAY #2
290μ
RELAY #1
SEE C-7-148
TRIGGER
LS-7
BS2-7-5
ROT. SOL. NO. 2
S12
SEE A-7-134A
2 SEC. TIME SWITCH NO. 2
#1 DECK
#2
LS6
LS5
LS4
DECK #3
#4
#5
#6
LS6 OPEN ON 32 POS. ONLY
LS4 & 5 OPEN ON POS. 29, 30, & 31
MANUALLY INITIATED SCAN SWITCH = BS2
NOTE: SWITCH POSITIONS REVERSED LEFT TO RIGHT
290μ
5Ω
RELAY #4
RELAY #3
SEE C-7-148
ALL GROUNDS TIED TO CHASSIS BUS BAR
P41 TO P45 ARE SWITCHCRAFT B3M 3PIN RECEPTACLES
RELAYS 1 THRU 4 ARE ALLIED CONTROL MHX 2155 28V. DC. DPDT. RELAYS #2 & 4 HAVE 0.2 SEC. DELAYED OPENING
MEASUREMENT SYSTEMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
TITLE CONTROL CIRCUITS
REF. DWG. D-7-130
PROJ. 71511
B ADD. RELAYS J.J.E. NOV. 17
C P37 WAS P39 J.J.E. DEC. 17
REV DESCRIPTION DATE
DR. BY J. J. Egan Sept. 9, '69
SCALE
C-7-131 -C

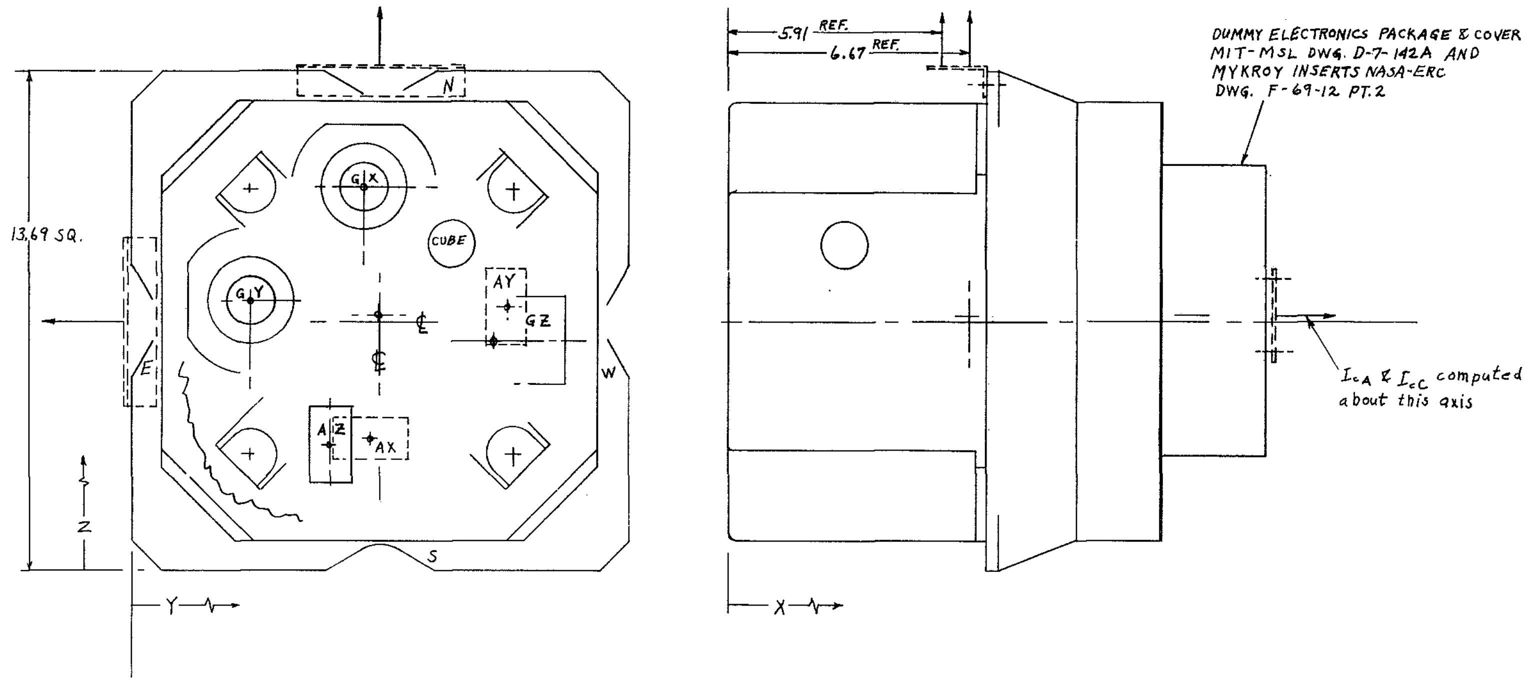

MARK WITH INK AS SHOWN
1 OF EACH ASSEM. X, Y, & Z
2-56 x 3/4 STN. STL. SOC. HD. (4)
Z
J52
CANNON DE-9S CONNECT.
1"
17/32
11/32
1/8
5/8 D x 1/4 DP. FLAT BOTTOM
45°
.938±.006
1 1/8 SQ.
3/16
±.006
1.000
2"
9/16
9/16
.100±.005 D. THRU (4) C'MILL 3/16 D. x 9/16 DP. RUN END MILL AWAY FROM ℄ TO GIVE 3/16 W. SLOTS AS SHOWN
4 6061-T6 ALUM.
MAKE 3
RdF #C3191-4 500Ω CP NICKLE
TEMP. SENSORS (3) EQ. SPACED ON 1/4"D. AND 1 IN BASE.
TO BE CEMENTED INTO .120 DR. x 1/2" DP.
HOLES WITH BACON INDUSTRIES FA13
EPOXY USING BA39 ACTIVATOR. HOLES
MUST BE FREE OF AIR BUBBLES. OVEN CURE
PER BACON INDUS. DIRECTIONS.
4
NASA-ERC DWG.
D69-7 PTS. 1 2 & 3
EXCEPT OMIT GRINDING,
HELICOILS, & HEAT TREAT.
MADE BY MIT-MSL
3/16
SPARE
AZS (SERVO)
AZT
AZL
1
2
3
3/4 LG. SPACERS (1/4" O.D.) & 4-40 x 1" FIL. HD. BRASS SCR'S. 2 OF EACH/ASSEM.
MINCO PROD. CO.
HEATER HR5026-A-135Ω (0.53" x 2")
SILICONE RUBBER)
AZT AZS AZL F15 HEATER SPARE
J52 -1 -2 -3 -4 -5 -6 -7 -8 -9
8" LEADS TIED INOFFENSIVELY
DENTRONICS HG 524 ST EL
TEMP. SENSOR 250Ω NICKLE A
F15
MAKE 3 ASSEMBLIES IDENTICAL
EXCEPT FOR LABELING
	MARKED	250Ω SENS.	SERVO SENS.	500Ω SENS.	RECEPT.	SERVO LEAD
PT. 1 X AXIS ACCEL.	X	F13	AXS	AXT	J50	AXL
PT. 2 Y " "	Y	F14	AYS	AYT	J51	AYL
PT. 3 (SHOWN) Z " "	Z	F15	AZS	AZT	J52	AZL
MEASUREMENT SYSTEMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
TITLE DUMMY ACCEL. ASSEM.
REF. DWG. D-7-115A
PROJ. 71511
DR. BY J.J. Egan DATE Oct. 21 '69
CH'K DATE
SCALE
DWG NO. C-7-141
REV NO -
REV DESCRIPTION DATE


EPS
T12
EPT T13
EPL & T14
T 11
T 10
N
2"
EXISTING HOLE IN ELECTRONICS HOUSING. DR. & C'SINK 11 SIMILAR HOLES SHOWN ON F69-12
℄
W
ALL TEMP. SENSORS RdF C.P. NICKLE-200 Ω T-10,-11,&-12 ARE PN200 OTHER 5 SENSORS BN200
1/4 R
10"
1/2 TYP
8"
3/8 THK 6061-T6 ALUM. MAKE 1
ALL THERMAL SENSORS RdF BN200'S PURE NICKLE-200 OHM NOM. AT 70°F.
P31 SEE C-7-144C
1 1/2
J36
12" LEADS WITH RANDOM COLORS
5 7/8
2 15/16
1 1/8
ANCHOR LEADS
T10
MYKROY 750 NASA-ERC DWG F 69-12 (2)
.334 REF.
T11
3/4
T13
T14
T12
SPARE
EPS (S=SERVO)
EPL (L=LEAD)
2 MINCO HK-913-P 60Ω HEATERS IN PAR. 30W. AT 28V.
1/4 x 5 1/2 x 8
NEW DUMMY ELECTRONICS PKG. (ALUM. COMPONENTS) 5 1/4 H x 7 3/4 x 8 3/4
BUD AC1418 ALUM. CHASSIS 8x10x2 1/2" - ALTER
9/16
ALTER EXISTING MIT MSL COVER
3/4 D (4)
3/4
HON. DWG. D34003359
THIS SIDE OBSOLETE
B INTERCHGD. T13 & T14
A GEN. CHGS.
DESCRIPTION
MEASUREMENT SYSTEMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
APPROVAL AND DATE
DO NOT SCALE FOR CONSTRUCTION
DUMMY ELECTR PACKAGE
71511
1=1
D-7-142-B



GZH
PLAT. REF.
Z GYRO ONLY
GZT
GZS
GZW
(SPARE)
-9 -10 -1 -2 -3 -4 -5 -6 -7 -8
ALTER EXISTING HONEYWELL
DUMMY GYROS DWG. D34003856 (3)
MARK 1 EACH
X, Y, OR Z
Z
1/4 D. x 1/4 LG. ALUM. SPACERS (2)
Z CONN. CANNON DAMA-15S (J53)
X&Y " " DE-9S (J54(Y) & J55(Z))
EXISTING BINDING
POSTS (4)
GZS
GZW
GZH 52 Ω
15W. AT 28V.
GZT
.015 BRASS LEAD
PROTECTOR (3)
7/8
AS REQD.
IN Z GYRO ONLY - 3/16 DR. THRU
PLASTIC & 9/64 DR. x 3/16 DP. IN ALUM.
FOR MINCO PROD. CO. #31A
PLATINUM TEMP. SENSOR.
SENSOR TO BE COATED WITH
WAKEFIELD #128 THERMAL
COMPOUND & MUST BE
REMOVABLE. (SEE A-7-147)
FACTORY CALIBRATED AT: 469.76 Ω AT 32°F.
3 - 500 Ω C.P. NICKLE TEMP. SENSORS
IN EACH DUMMY GYRO. R&F C3191-4
3/16 DR. THRU PLASTIC. .120 DR. x 1/2 DP. IN
ALUM. SECURE WITH BACON INDUST.
FA13 EPOXY & BA39 HARDENER.
AVOID AIR BUBBLES. CURE 2 HRS.
AT 160° & 4 HRS. AT 200°F.
ALTER 3 HONEYWELL DUMMY
GYROS DWG. D34003856
MEASUREMENT SYSTEMS
LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
TITLE DUMMY GYROS
REF. DWG. D-7-115A
PROJ. 71511
DR BY J. T. Egan DATE Oct. 30 '69
CHK DATE
A INTERCHNGD. X & Z J.T.E. 12/17/69
REV DESCRIPTION DATE
SCALE 1:1
DWG NO C-7-145
REV NO A


CAPSULE A-7-137A
BS1 POS.
1
GXT
2
GYT
23
T2
24
T9
28
F2
29
F10
BS2 POS.
29&30
PLAT.
SEE A-7-147
10 ft.
J37 (TEMPORARY
GREY
GXT
BROWN
GYT
ORANGE
T2
VIOLET
F2
BLUE
F10
YELLOW
PLAT.
WHITE
COM.BR.
RED
COM.V
1
2
15
16
22
28
33
34
35
36
37
J38
JACK ONLY
GREEN
T9
4
MEASUREMENT SYSTEMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
TITLE
TEST CAPSULE
REF. DWG.
PROJ.
71511
DR. BY
J. J. Egan
DATE
Nov. 6 '69
CH'K
DATE
SCALE
DWG NO.
C-7-146
REV NO
-
REV
DESCRIPTION
DATE



			WEIGHT	C G X	C G Y	C G Z		I_c	I_n	I_e
A	Thermal Test Model (complete)		60.5 Lb.	6.67	6.87	6.96 in.		2.82	3.04	2.91
B	Test Model without DEP, cover, & Mykroy		51.7	5.91	6.83	6.91		2.48	2.25	2.22
C	Dummy Electronics Package only ~~(incl. cover)~~ (M I T - M S L Dwg. D - 7 - 142 A)		7.05	10.36	7.25	7.12	incl. cover	.336	O	O
D	Electronics Cover only		1.82	12.85	6.46	7.17				
								I_{cm}	I_{cm}	I_{cm}
E	[illegible]	X Axis	1.[illegible]	2.90	[illegible]	[illegible] 7.25		.0025	.0032	.0032
		Y Axis	"	2.90	3.17	[illegible]		.0025	.0032	.0032
		Z Axis	"	2.22	9.82	6.44		.0032	.0032	.0025
F	Dummy Accelerometer	X Axis	.24	5.47	10.19	7.22		.00027	.00013	.00027
		Y Axis	"	5.47	6.47	3.50		.00027	.00027	.00013
		Z Axis	"	8.13	5.31	3.37		.00027	.00013	.00027

THESE VALUES MAY BE COMPUTED FROM AVAILABLE DATA BUT THE NUMBERS WOULD BE MORE MEANINGFUL IF REFERRED TO A NEW FINAL PACKAGE CG.

MEASUREMENT SYSTEMS LABORATORY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY	TITLE: C.G. & INERTIA MEAS.
	REF. DWG. — PROJ. 71511
	DR BY: J. J. Egan — DATE: Dec. 15 '69 — CHK — DATE
REV / DESCRIPTION / DATE	SCALE: .484 / 1 — DWG NO: C-7-152 — REV NO

12/15/69
T. Egan
See MIT-MSL DWG C-7-152

Model supported by .125 D. x 39 1/2" Lg.   #302 STN, STL, Torsion Wire

Shear modulus test $n = 10.3 \times 10^6$ (book value 10.6×10^6)

P (Test Mass) = 21.6, 21.6, 21.8   sec/20 cycles
Computed I = .183 in. Lb. sec^2

Test Mass = STL, CYL.   6.00 "D. x 2" THK = 15.75Lb.

P (Axial) (Complete thermal test model)   42.4, 42.3, 42.5 sec/10 cycles

P (North up) (Complete)   44.0, 44.0, 43.8 sec/10 cycles

(Less Dummy Electronics Package & its Cover)   37.5, 38.0, 37.8 sec/10 cycles

P (East up) (Complete)   43.0, 42.9, 43.0 sec/10 cycles

(Less DEP & Cover)   37.8, 37.4, 37.6 sec/10 cycles

P (Axial) DEP with Mykroy & Cover   29.3, 29.1 sec/20 cycles

No radial restraints at lower end.

Inertia test data Ref. C-7-152